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CANADA
DEPARTMENT OF MINES
HON. LOUIS CODERRE, MINISTER; R. G. MCCONNELL, DEPUTY MINISTER.

MINES BRANCH
EUGENE HAANEL, PH.D., DIRECTOR.

Electrothermic Smelting of Iron Ores in Sweden

BY

Alfred Stansfield, D.Sc., A.R.S.M., F.R.S.C.

OTTAWA
GOVERNMENT PRINTING BUREAU
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LETTER OF TRANSMITTAL.

Eugene Haanel, Esq., Ph.D.,
Director Mines Branch,
Department of Mines,
Ottawa.

Sir,—

In accordance with your letter of instructions of May 19, 1914, I proceeded to Sweden in June. I visited the three important works at which the electric smelting of iron ores is in operation, and called upon General Major Geijer, L. Ljungberg, Esq., Assar Grönwall, Esq., and other gentlemen to whom you gave me introductions. In addition to this I investigated a new steel-making furnace in Sweden, and one electric iron-smelting plant in Norway.

I wish to express my obligation to the management and engineers of the plants I visited, and to other gentlemen whom I met in Sweden and Norway, for the information they placed at my disposal, and for the kind reception which was everywhere extended to me.

I beg to submit, herewith, the report of my investigation.

I have the honour to be,
Sir,
Your obedient servant,
(*Signed*) **Alfred Stansfield.**

Montreal,
January 2, 1915.

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ELECTROTHERMIC SMELTING
OF IRON ORES IN
SWEDEN.

ELECTROTHERMIC SMELTING OF IRON ORES IN SWEDEN.

PART I.

GENERAL REPORT.

INTRODUCTORY.

The present investigation was made to obtain information with regard to the economic or commercial operation of the electrothermic iron-smelting furnaces in Sweden: such information being of great value in view of the possibility of establishing an electric iron-smelting industry in Canada.

For this purpose the writer visited Sweden during June and July 1914 and inspected the principal smelting plants, besides meeting many engineers and other gentlemen who were well informed in regard to electric iron-smelting.

The scope of the visits was extended to include the furnaces at Notodden in Norway, and a new electric steel-making furnace in operation in Sweden.

ELECTRIC FURNACES FOR IRON SMELTING.

At the present time there are two main types of electric furnace for smelting iron ores:—

(1) The Elektrometall furnace, in which the ore is preheated and partially reduced in a shaft before it reaches the smelting chamber; the heating of the ore in the shaft and the chemical reduction of the iron in the ore being materially assisted by the circulation of the furnace gases, which is characteristic of this furnace.

(2) Furnaces of the Helfenstein, Californian, and Tinfos type, in which there is no provision for preheating the ore. Any shafts employed are merely for the purpose of introducing

the ore charge conveniently, and the main object of the design is, to obtain a large and substantial furnace for smelting iron ores by electrical heat.

In Sweden, the Elektrometall furnace has been largely used, and is in regular commercial operation, but experiments are being made with a modified Helfenstein furnace. In Norway, the Tinfos furnace is in operation on a moderate scale.

ELEKTROMETALL FURNACE.

This has been described by many writers[1], and it will, therefore, be sufficient to give a short account of the most recent construction of this type of furnace. The crucible is circular, and provided with one tapping hole, from which both the slag and metal are withdrawn (see Plates III and IV) an additional hole being available for use in emergency. The metal and slag are separated by a dam as they flow; the metal being cast into pigs, (see Plates IV, V, and VI) or taken in a ladle to the Bessemer converter or the open-hearth furnace. The crucible is lined with fire-brick like the ordinary blast-furnace, and not, as in the earlier furnaces, with magnesite. The stack of the furnace is constructed in a steel shell, and is supported on steel beams, independent of the crucible. The shaft is reduced to a neck, where it enters the crucible, so as to leave a free space in the crucible for the introduction of the electrodes. The tendency is to increase the width of this neck, particularly when powdery ores are to be treated, as this leaves a freer course for the passage of the gases up the shaft.

The arch of the crucible is constructed of fire-clay bricks, (not of magnesite or silica bricks). The arch is cooled below by the introduction of cool gases from the top of the furnace, and it is also cooled on its upper surface by cold air from a number of pipes, as shown in Plate I. The arch is the least substantial part of the furnace, but repairs to it can be effected without great delay, by introducing some cold ore-charge into the crucible, and using this as a temporary support for the new brickwork.

The electrodes are circular, about 600 mm. (2 feet) in

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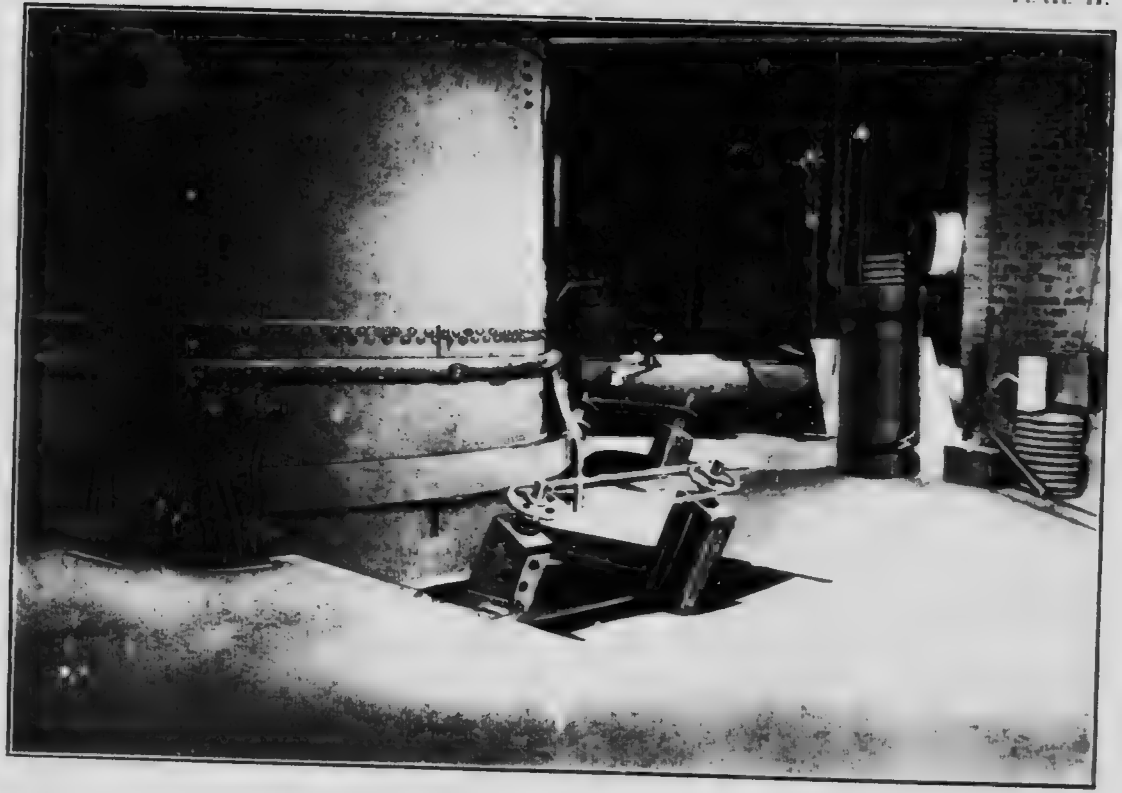
[1] References given in bibliography at the end of this Report.

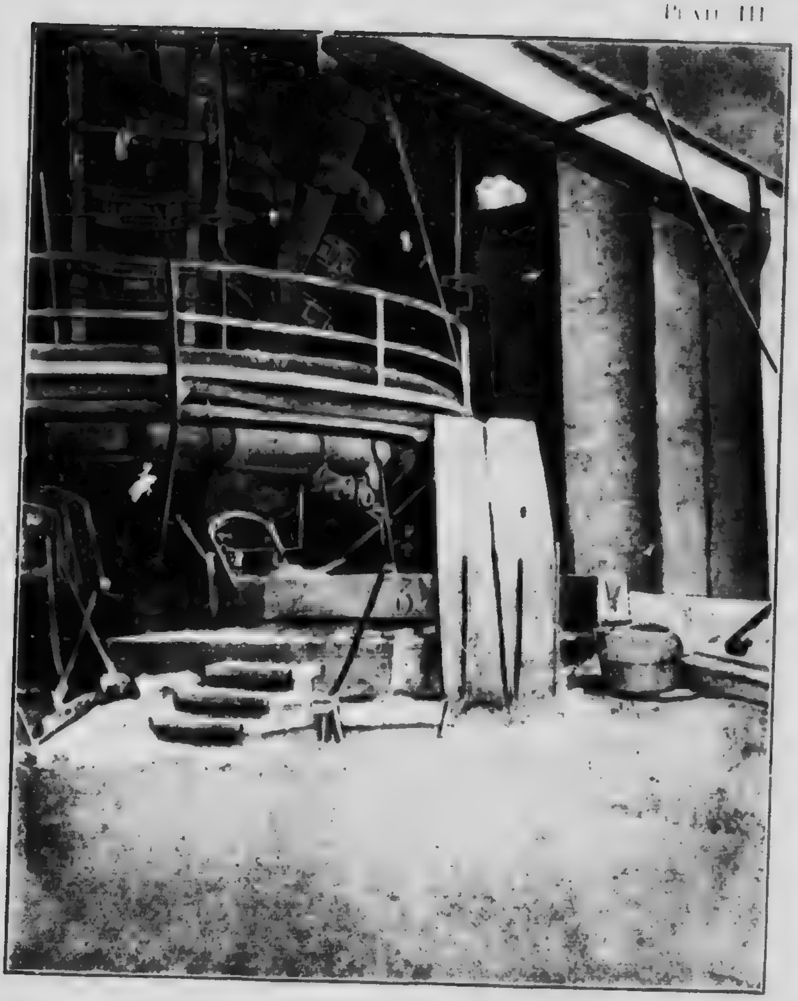
Elektrometall furnace: showing arch of crucible, and electrode contacts.

PLATE II.



Elektrometall furnace: showing electrodes.

PLATE III



Elektrometall furnace: showing electrode guides, and tapping hole

diameter, and 4 or 5 feet long (see Plate II) and can be attached end to end by moulded carbon nipples, which are screwed into threaded holes in the ends of the electrodes. The electrode holders are substantially the same in all Elektrometall furnaces, (see Plates I, II, and III) and consist of two inclined guides, between which the electrodes lie, supported by guide rollers. At the bottom of these guides is the water-cooled collar, built into the furnace arch. This collar is supported from above, so that it does not press on the arch, and is packed around the electrode with asbestos, so that the gas does not escape from the furnace. Above this, comes a water-cooled contact ring, consisting, essentially, of a number of metal blocks, forming a flexible collar that can be tightened around the electrode. Each block is connected to one of the copper bus-bars by a short piece of flexible cable. Above the contact ring, which is close above the furnace arch, is a clamping ring for feeding the electrodes. This ring grips the electrode, and can be made to move up or down the guides by a pair of long screws. The two screws are operated from above by a ratchet (Plate II) and they are connected together by gearing, so that they must turn at the same rate. The electrodes do not, as a rule, need moving more than once in two or three days.

The larger furnaces have six electrodes, supplied with three-phase current from three transformers. Each transformer is connected to two diametrically opposite electrodes, so that the electric current tends to pass between these instead of between adjacent electrodes, as in the earlier arrangement. The voltage of each transformer can be regulated separately by means of taps on the primary windings, and a nearly constant power can thus be supplied to each pair of electrodes in spite of changes in the electrical resistance between them. The regulation of the electric power is thus effected by changing the voltage of the supply and not by moving the electrodes up and down. When an electrode has become too short, which is indicated by the voltage between it and the material in the furnace, it is fed farther in, as described above.

The circulation of the furnace gas is an important feature of this type of furnace. The gas is withdrawn from the top of the furnace, passed through dust catchers, then through pipes, where it meets a spray of water, then through a centrifugal fan, also supplied with a water spray, and finally, through a separating chamber for the removal of the entangled water.

In some cases a Roots blower is used to ensure a constant flow of gas, but in other cases the rotary washing fan is depended on for effecting this purpose. The washed gas is supplied to six tuyeres entering beneath the furnace arch and between adjacent electrodes. These tuyeres cannot be utilized for peep holes, as in the blast-furnace, because the dirt in the gas quickly obscures any glass windows. The operation of the furnace depends very largely on the gas circulation. Increasing the circulation raises the temperature in the shaft, facilitates the reduction of the ore, raises the percentage of CO_2 in the escaping gases, and increases the economy both of electric power and of fuel; but on the other hand it increases the consumption of electrodes as these are attacked by the CO_2 in the circulating gas.

The gas escaping from the Swedish furnaces is not fully utilized at present, but it will probably be employed for heating open-hearth furnaces, or for similar purposes, and this will represent an important economy in the operation of the furnace.

HELFENSTEIN TYPE OF FURNACE.

Under this heading may be grouped a number of electric smelting furnaces which resemble the Helfenstein ferro-silicon furnace.[1] The best known example is the furnace built by the Noble Electric Steel Company, at Heroult, California, U.S.A.[2] This type of furnace consists of a large smelting chamber, usually rectangular in plan, having a number of vertical electrodes, which enter through the roof. The ore charge is introduced through a number of chutes, but no attempt is made to preheat the ore before it enters the smelting chamber. The Helfenstein furnace[3] cor-

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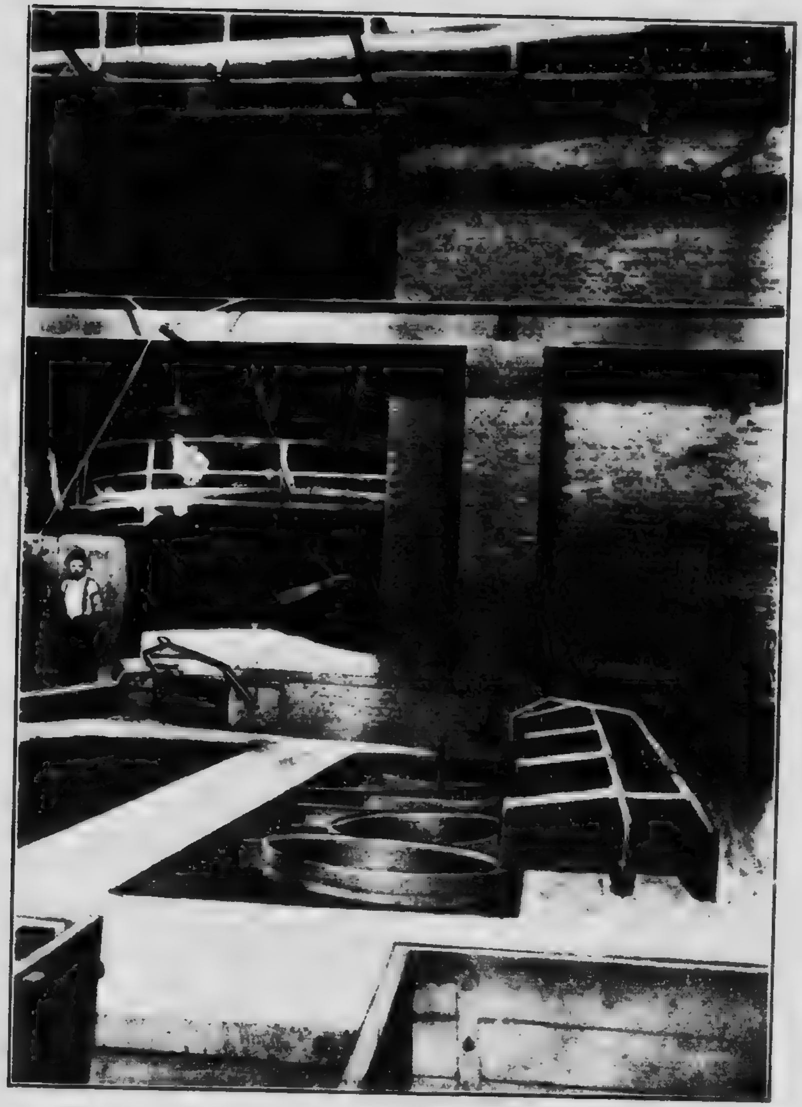
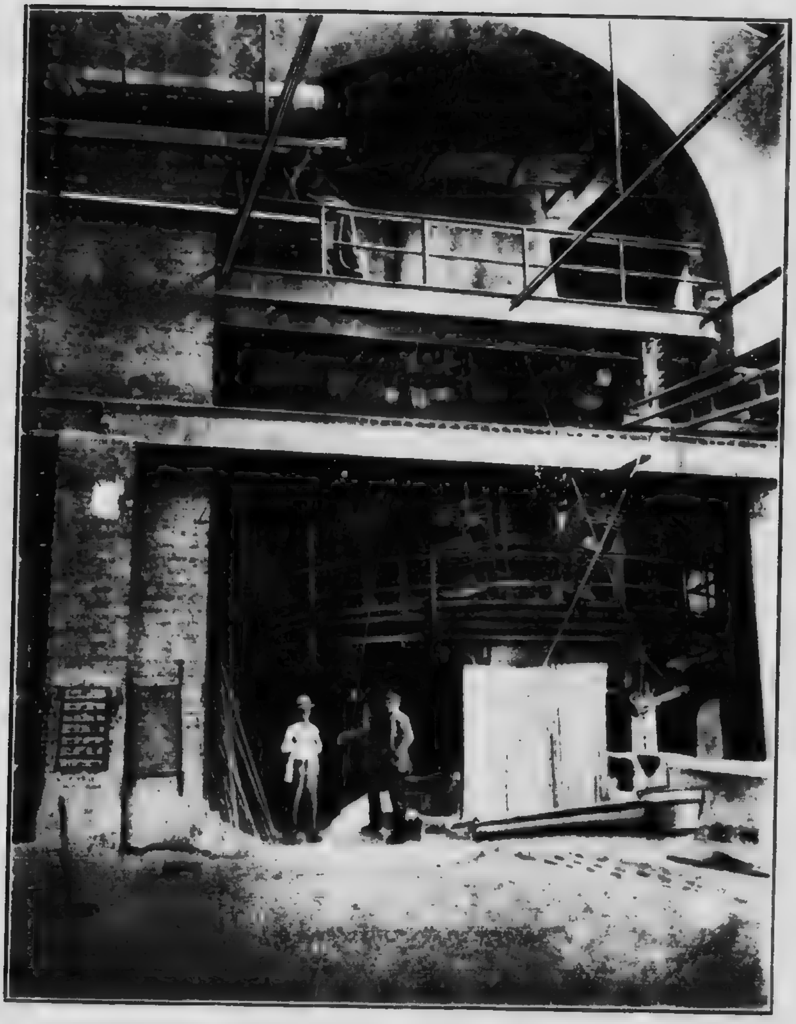
[1] Met. and Chem. Eng. X, 1912, p. 686.

[2] Met. and Chem. Eng. XI, 1913, p. 383.

[3] Dr. E. J. Ljungberg informed me at the time of my visit that in a year's time he would be able to give me full information with regard to the Helfenstein furnace. I therefore wrote to him under date of August 3rd, 1915, in the hope of obtaining some information that could be incorporated in this Report. I have now received a reply from which I regret to learn that Dr. Ljungberg died a few months ago. The writer adds that they are still prevented from giving any information about the furnace at Domnarfvet.

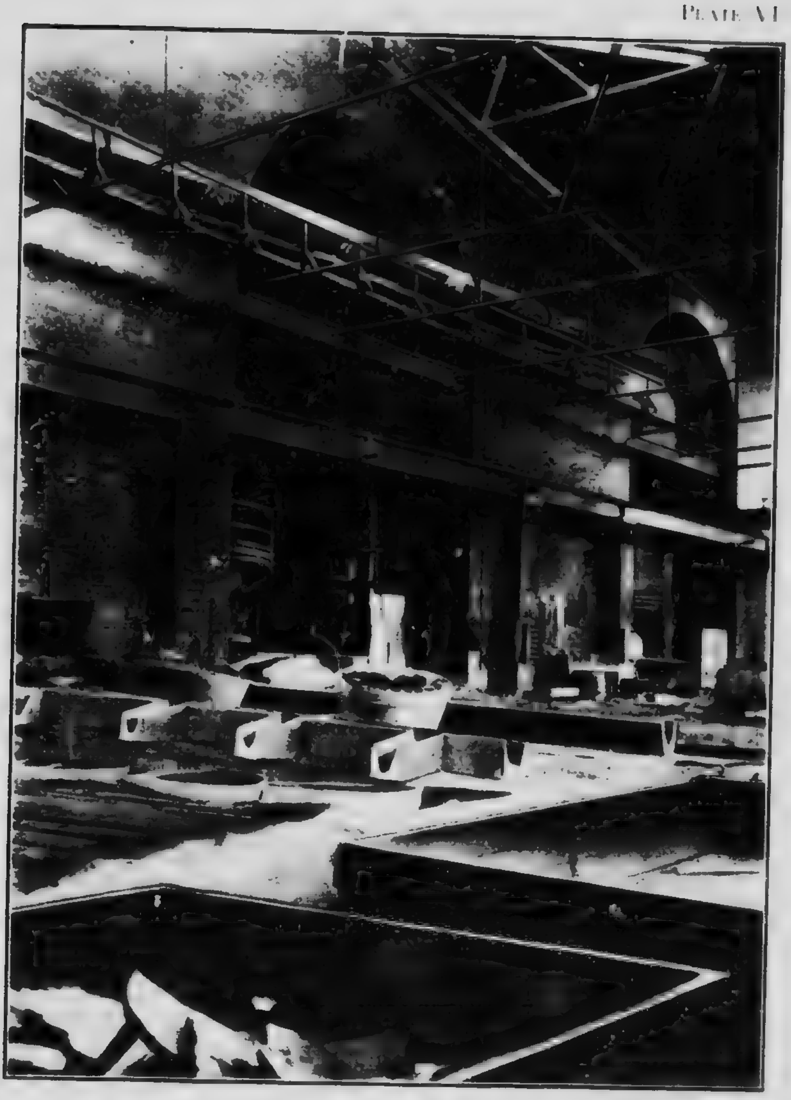


Elektrometall furnace: showing disposal of metal and slag



Elektrometall furnace: general view.

PLATE VI



Elektrometall furnace: view at casting house.

responds roughly to the crucible of the Elektrometall furnace; the large shaft of the latter being replaced by comparatively small charging chutes. The economy obtained by the large shaft and gas-circulation of the Elektrometall furnace is deliberately abandoned in the Helfenstein furnace; attention being centred, instead, on the provision of a large and substantial smelting chamber, in which the smelting can be carried out rapidly by electric energy. In the Elektrometall furnace the shaft is much larger than the crucible, and its removal renders it easier to construct a smelting chamber in which a large amount of electrical energy can be utilized.

The economy of electric furnaces increases with the amount of power employed, and by building a furnace to use say 12,000 h.p., instead of 4,000 h.p., the increase in economy, so obtained, may offset the loss of economy due to the want of a preheating stack. In addition to this it must be remembered that the gas given off from this type of furnace will be larger in amount and richer in carbon monoxide than the gas from the Elektrometall furnace, and it will have a greater value for heating open-hearth or other furnaces.

The Stora Kopparbergs Bergslags A/B have been experimenting for some time with a furnace of the Helfenstein type, at Domnarfvet, and have ultimately been successful with it; although it has not yet passed the experimental stage, and particulars cannot be made known. In the first place the furnace was built on lines similar to the Helfenstein ferro-silicon furnace; but important modifications have been found necessary before it could be successfully employed for smelting iron ores.

In Norway, the Tinfos Jernverk A/S are operating, at Notodden, three single-phase furnaces of about 1,600 h.p. each. The "Tinfos" furnace (see Fig. 2) consists of a long rectangular smelting chamber, having an inclined chute along each long side, to supply the ore charge. The roof, between these chutes, is carried by means of two water-cooled beams running the length of the furnace, and placed just far enough apart to admit the rectangular electrodes, of which there are three connected to one pole of the supply. The opposing electrode lies in the bottom of the furnace, and is covered with a bed of rammed coke, which forms the working bottom, and has been found to last very well. Particulars of the operation of these furnaces are given later in the report; but on account of the small amount of power employed, and of the different conditions which obtain, no useful comparison can be drawn between the efficiency of these furnaces and that of the Elektrometall furnaces.

In comparing the Elektrometall with the Helfenstein type of furnace, it should also be pointed out that difficulty is experienced with the former when using very powdery ores, owing to the charge in the shaft becoming too compact to allow the passage of the gases. This difficulty must be far less serious with a furnace of the Helfenstein type. A similar comparison may be made in regard to the use of coke in these furnaces. The Elektrometall furnaces all use charcoal as a reducing agent, and attempts made to use coke instead of charcoal in these furnaces have not been very successful. Less difficulty is experienced in the use of coke in a simple Helfenstein furnace, and coke is used regularly in the Tinfos furnaces.

The quality of high class Swedish pig-iron, and its value for steel-making, cannot be entirely determined by ordinary chemical analysis, and until the point is settled by direct observation it will be unsafe to conclude that pig-iron made by rapidly smelting the raw charge in a high-powered furnace will equal in quality the product of the Elektrometall furnace with its preliminary shaft-reduction, and more moderate rate of smelting. The Elektrometall furnace has been found to yield iron of the highest quality, and the Stora Kopparbergs Bergslags have decided to use this type of furnace for making the famous Dannemora iron at Soderfors, in spite of their success with the Helfenstein furnace.

ELECTRIC IRON SMELTING IN SWEDEN.

The electric iron-smelting industry is well established in Sweden. Five furnaces are in regular commercial use, and at least three more are in course of construction.[1] It is true that the output of these furnaces is not very large, but they have as large an output as the charcoal blast-furnaces which they replace.

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[1] The figures just quoted refer to the time of my visit to Sweden in the year 1914, shortly before the war. Mr. J. O. Böving of the Electro-Metals, Ltd., writing under date of June 4, 1915, enumerates seven furnaces in operation, and ten more in course of construction.

The Swedish iron industry consists, in the main, of smelting pure Swedish ores with charcoal in blast-furnaces of very moderate dimensions, and small yield. This industry has been commercially profitable on account of the high quality and consequent high price of the resulting pig-iron. The output of this high quality iron has been restricted by the increasing price, and even more by the increasing scarcity of charcoal available for smelting the iron.

The electric furnace has now become a dependable and economic appliance for regular commercial use. The iron obtained from it is even better than that from the charcoal-iron blast-furnace, using the same ores and fuel. The cost of making the iron, using cheap Swedish water-power, is somewhat less than in the charcoal blast-furnace. The amount of iron that can be made with a definite supply of charcoal is three times as much in the electric furnace as in the blast-furnace. These considerations appear to represent the foundation of the present electric iron-smelting industry in Sweden.

The Elektrometall furnaces can replace, to advantage, the small charcoal blast-furnaces in which high-grade Swedish iron was made; but it must be remembered that their output is small. The largest now in operation, the 4,000 h.p. furnace at Domnarfvet, has an average daily output of about 30 tons. The smallness of the scale on which these furnaces operate may not be harmful in the charcoal-iron industry, because quality rather than quantity is aimed at, and because charcoal furnaces must always be of moderate dimensions. Such furnaces, however, cannot compete, commercially, with a modern coke blast-furnace of 400 or 500 tons daily output. It must also be remembered that attempts to use coke instead of charcoal in the Elektrometall furnace have so far been unsuccessful, though it is expected that the difficulties encountered may be overcome by building the furnace shaft somewhat wider and lower. This change is needed because coke is far less bulky than charcoal and the charge is therefore less open and obstructs the passage of the gases up the shaft. Burnt lime is found to be better than limestone for flux in furnaces using coke, and the reason for this is, doubtless, that it makes the charge more open.

ELECTRIC IRON SMELTING POSSIBILITIES IN CANADA.

What may be learnt from the conditions in Sweden with regard to the possibility of establishing electric iron smelting in Canada?

1. On account of the high cost of production, the difficulties attending the use of coke in the Swedish furnaces, and the small size of these furnaces, we may say that at present there is no evidence to show that electric iron smelting can be undertaken on a large scale in competition with the existing blast-furnace industry.

2. If pure ores can be obtained at any point, together with charcoal and cheap water power, it should be possible to produce economically a high grade charcoal iron. Data are given in this report which will enable estimates to be made of the cost of such electro-pig-iron. The purity of the available ores and the quality of the resulting pig-iron are matters to which special attention should be directed, and the analyses given in this report will serve to show the conditions under which the high grade Swedish iron is produced at a profit in the electric furnace.

It may be added that much of the Swedish iron is utilized in Sweden for the production of special qualities of steel and wrought iron; the uses of high quality charcoal-iron would have to be considered, and perhaps even discovered, before beginning in Canada a large production of a rather expensive product.

3. Canadian ores do not in general even approach the Swedish standard of purity: thus the ore in the Bristol Mine, Que.[1], contains from 1 per cent to 2 per cent of sulphur; while the Swedish ores carry only a few hundredths of 1 per cent. The Swedish practice, therefore, does not throw any light on the production of pure iron from sulphurous ores. It may be stated, however, as the result of experiments by Dr. Haanel[2]

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[1] [illegible] Co., Que., by E. Lindeman, Bull. 2 [illegible] Ottawa, [illegible]

[2] Dr. Eugene Haanel, Report on Experiments at Sault Ste. Marie, Department of Mines, Ottawa, 1907.

and others, that sulphur can be eliminated very thoroughly in the electric furnace, although the cost of smelting will certainly be much higher than when pure ores are used. It remains to be ascertained also whether the "Elektrometall" furnace is well suited for this purpose.

4. It seems quite possible, that using ores of moderate purity, and a cheap fuel such as charred wood refuse, or gas coke, a good quality of iron suitable for car-wheels could be made at a profit in one or another of the electric smelting furnaces at present in use.

COMMERCIAL EFFICIENCY OF THE ELEKTROMETALL FURNACE.

In Part II of this report, numerical data are given for the consumption of electric energy, charcoal, electrodes, and labour, per ton of iron; but a few general remarks must first be made with regard to the application of these data.

The first point to consider, is that of the regularity of operation of the furnace. Suppose that a smelting plant is equipped with one furnace, and had contracted to pay for 3,000 K.W. of electrical energy. What proportion of the amount paid for will actually be utilized in the furnace while it is running, and what proportion of the total time will be wasted owing to stoppages of the furnace for minor repairs, relining, or rebuilding, and holidays? We may suppose that the plant cannot draw more than 3,000 K.W. for any appreciable length of time, and that the object of the furnace men is to keep the whole load (furnace, motors, and light) as close to 3,000 K.W. as possible.

In the first place, it will be noted that the electric power is supplied at a high voltage (say 10,000 volts), and transformed to about 80 or 90 volts, for use in the furnace. This involves a loss of perhaps 3 per cent on the whole power; but as all the power measurements are made on the high voltage side of the transformers, there is no correction on this account to be applied to the figures quoted for kilowatt hours per ton of iron.

The amount of electric energy consumed in running motors and lighting the plant, is about 2½ per cent of the whole supply: that is, 75 K.W., or 100 h.p. for the plant having one 3,000 K.W. furnace.

The next point to consider is the steadiness of the furnace load, as this determines how close the mean load can be brought to the maximum. Figure 1 is a reproduction of an average record of the wattmeter for one furnace, and gives an idea of the extent of the irregularities in power, and the causes of these. The furnace is tapped once in six hours, and as molten iron and slag are removed from the furnace, the electrical resistance increases, while the current and power decrease. The attendant corrects this, more or less promptly, by raising the voltage of the supply; the power increases, and soon becomes too great, then the regulating process has to be reversed. In addition to the large disturbance caused by tapping, there are minor changes due to the settlement of the charge in the furnace, and similar causes. The regulation of the electrodes also necessitates a temporary drop in the power consumption. In a six electrode furnace the current is cut off one pair of electrodes, thus losing nearly one-third of the power, while either of these are being regulated, an operation that occupies a few minutes. In interpreting the record, we may assume that the maximum power available is 2,700 K.W., and it will be clear that the average power utilized is less than this maximum by some 200 K.W. or 7½ per cent of the maximum.

It will be safe to assume that the average power utilized while the furnace is in operation is about 92 per cent of the maximum; and deducting further the 2 per cent for lights and motors, we find that the furnace utilizes during operation about 90 per cent of the power supplied to the plant[1].

There remains the very important consideration of holidays and stoppages for repairs and relining; because during these periods the electric power is being paid for, although no iron is made. Reports on the Domnarfvet and Trollhättan furnaces, given later, show that the holidays—during which the furnace must be banked—amount to some 9 or 10 days in the year (2½ per cent), and the other stoppages to two or three weeks, making a total loss of time of 8 or 9 per cent of the whole.

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[1] If we neglect transformer losses, as explained above, by measuring all the power on the high voltage side of the transformer.

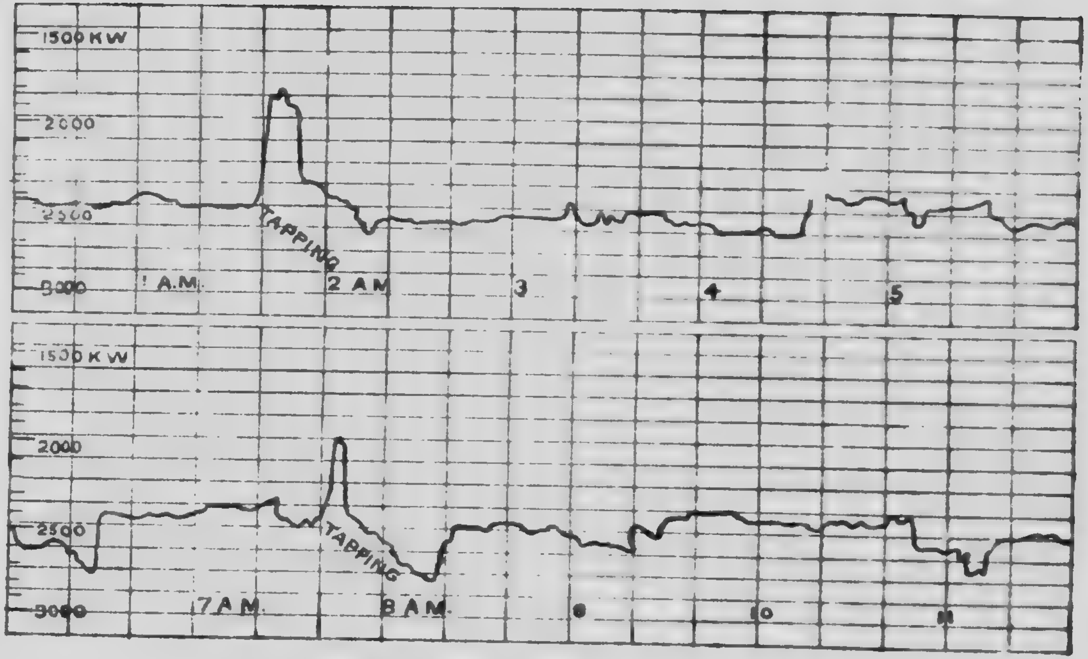

Fig. 1 — Electric steel furnace. Wattmeter record for 12 hours.

Combining these figures, we find that the power utilized by the furnace amounts to some 82 or 83 per cent of the gross amount paid for.

In this case, perhaps 5 per cent of the whole time represents stoppages for important repairs or relining, in which the furnace is allowed to cool, and must then be reheated. This loss of time could be avoided, in part, by providing an additional furnace, which could be started as soon as the other needed stopping for repairs; but such practice would hardly be economical, as it would mean duplicating the furnace plant in order to save 5 per cent of the time; if, however, the plant consisted of three or four furnaces, it might pay to have one extra furnace ready to be put to work when any of the others needed repairs. In operating three or more furnaces, also, it should be possible to utilize a larger proportion of the maximum power, as the irregularities produced by tapping, for example, would be relatively less important, and it could be arranged that no two furnaces would be tapped at the same time. Under these conditions, it would be possible to ensure that the furnaces could utilize some 90 per cent of the whole power for which payment is made.

The degree of continuity of operation attainable is of great importance, not only in regard to the cost of electric power, but also in relation to labour, management, interest on capital, and fixed charges.

The figures for power consumption given in Part II of this report, refer to the power actually used in the furnace (and transformer), while making one ton of pig-iron. These figures should be increased in about the ratio 100/82 to find the number of kilowatt-hours really chargeable for one ton of iron, or the number of tons of iron obtainable for each horse-power year that is paid for.

The amount of electric energy required for making one ton of pig-iron depends both upon the kind of iron made and upon the percentage of iron in the ore. Grouping the results, we find:—

(1) At Domnarfvet and Trollhättan, from ores of 58 to 60 per cent iron, basic Bessemer iron needs 2,245 K.W. hours, while acid open-hearth iron needs 2,116; or, an average figure of 2,200 K.W. hours.

(2) At Domnarfvet and Hagfors, from ores of 50 per cent iron, acid open-hearth iron requires 2,500—2,600 K.W. hours at one plant, and 2,500 K.W. hours at the other; or, 2,500 K.W. hours, as an average.

It appears that for these classes of iron the effect of the richness of the ore is more pronounced than any difference between the grades of iron. To make grey pig-iron for foundry use would, however, necessitate a decided increase in the power consumption, as shown in the table of costs by Mr Grönwall

Correcting the figures 2,200 and 2,500 in the ratio 100/82 we get 2,700 and 3,050 K.W. hours, or 0·41 and 0·47 h.p. year, as the amount of electrical energy to be paid for in order to obtain one ton of such iron from a 60 per cent and a 50 per cent iron ore. It will be clear that, if we include the still higher figures representing the cost of foundry irons, the effective consumption of electrical energy for a ton of pig-iron is, under present conditions, nearly one-half of a horse-power year. The figure 2,400 K.W. hours, given by Mr. Grönwall in his estimate for electric white charcoal iron from a 60 per cent ore, could be obtained from the observed consumption 2,200 by the use of the factor 100/90, which is possible under very favourable conditions, or from a lower figure, 2,040 and the factor 100/85. It may be mentioned that the best electrical efficiency, as well as the largest output from a furnace, will be obtained by raising as far as possible the electrical input. The grade of iron obtained under these conditions may not be as good as with a lower power, and the life of the furnace lining will certainly be less. These considerations should not be forgotten in regard to the electrical economy of a furnace, and the figures quoted do not necessarily show the greatest economy that is possible with the Elektrometall furnaces.

The consumption of charcoal is 23·6 to 23·95 Hl., say 23·8 Hl., or 53 (heaped) bushels[1] per ton of white pig-iron from 60% ore at Domnarfvet and Trollhättan. At Hagfors from a 52% ore only 21 Hl. of charcoal is needed, or 47 (heaped) bushels per ton of iron. Taking the hectolitre of charcoal to weigh 15 Kg. (when dry), we have 357 and 315 Kg. per ton. Mr.

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[1] See table of weights and measures at end of this report

Grönwall estimates 340 Kg. which falls between these figures, and 370 Kg. for grey pig-iron.

The consumption of charcoal depends on the kind of ore, (hematite would need more than magnetite), and on the percentage of CO_2 in the furnace gases; the more CO_2 in the gases the less the consumption of charcoal. For this reason the circulation of the gases through the furnace reduces the consumption of charcoal. Furnaces of the Helfenstein type, which have no shaft for reduction of the ore, and no circulation of gases, will have a decidedly larger consumption of charcoal; but on the other hand they supply a large quantity of valuable gas which is available for heating other furnaces. The gases from the Elektrometall furnaces at Hagfors have been used for heating open-hearth furnaces, and their value has been stated to be 50c. to 75c. per ton of pig-iron made in the furnace.

The consumption of electrodes has decreased during the last few years. Those now in use, which are supplied by German manufacturers, are cylindrical, and are composed largely of anthracite coal. Their diameter is 550 or 600 mm.; they are supplied in lengths of 1·5 or 2·0 metres, and moulded carbon nipples are provided, for uniting them end to end. There are, therefore, no unused stubs, which in the earlier reports represented the large difference between the "gross" and the "net" consumption of electrodes; there is still a small difference however, which is due to the breakage of electrodes in handling.

The figures quoted in this report for the gross consumption of electrodes, are 7·0 Kg., 6 Kg., 8 Kg., and 4·64 Kg. per ton of pig-iron, and more recent figures are as low as 3 Kg. per ton. Mr. Grönwall quotes 6 Kg. (for white charcoal iron).

It may be mentioned that the circulation of the gases in the Elektrometall furnace, while economizing charcoal, increases the loss of electrodes; furnaces having a rapid circulation showing a greater electrode loss than those with a slow circulation.

TECHNICAL EFFICIENCY OF THE ELEKTROMETALL FURNACE.

The Elektrometall furnace has been successfully developed in Sweden, and is in regular commercial use; but other furnaces of entirely different design are being tried in Sweden and California; it is, therefore, very interesting to ascertain the efficiency of the Elektrometall furnace, and to consider whether other types of furnace might be expected to have a higher or a lower efficiency.

The Elektrometall furnace consists essentially of a smelting chamber, (or crucible), in which the charge is finally melted down by electrical heat; and a shaft in which the charge is heated and the ore partly reduced, by heat rising from the crucible. The heat is carried up by gases produced by the reduction of the ore, and this action is assisted by returning some gas from the furnace top to the crucible, so as to increase the stream of gases up the shaft. The other furnaces consist of the smelting chamber only; the shaft being non-existent, or very much reduced in size, and there is no circulation of the gases.

The large shaft of the Elektrometall furnace depends for its effectiveness on the circulation of the gases, as otherwise the contents would not be sufficiently heated, so that the question to be investigated resolves itself into the *desirability of the gas circulation system.* Does the circulation of the gases cause a large enough economy to justify the expense and inconvenience of the large stack, and the circulation apparatus?

Messrs. Leffler and Nyström have made elaborate calculations of the efficiency of the Trollhättan furnace for four periods ranging from Nov. 16, 1910, to October 1, 1911; and the writer has made similar calculations for a later period. The results of these five calculations are given in the following pages, and show the pe[illegible] of the electrical energy supplied that is utilized for each [illegible] he reduction operation, or that is lost in various ways. T[illegible] tables show among other things:—

(1) The heat utilized in the reduction of the iron, melting the pig-iron and slag, and in other necessary parts of the smelting operation, amounts to from 63 to 74 per cent of the whole electrical supply; this figure increasing in the later periods.

(2) The principal source of loss shown in the table, is the radiation of heat from the roof and other parts of the furnace and the heat lost in the cooling water supplied to electrode holders,

collars, and other parts. These losses varied from 31 to 19 per cent in the tests; decreasing in the later periods.

(3) The writer has calculated in each case, and added to the table, the potential energy or calorific power of the gases escaping from the furnace top. The amount of this varies from 84 to 74 per cent of the heat-equivalent of the electrical supply, and is, in each case, *more than the whole of the heat utilized in the smelting operation.*

The object of the gas circulation is to utilize as far as possible, *in the furnace stack*, the reducing and heating power of the carbon monoxide in the furnace gases; but even when this has been done to the greatest extent that is practicable, the remaining gas has a heat value greater than the net heat requirements of the smelting operation, or about 75 per cent of the whole electrical supply.

(4) The sensible heat carried out of the furnace by the escaping gases is unimportant, (owing to the low temperature of the furnace top), and no considerable loss of heat is occasioned in the same manner by the gas circulation system.

Tables are published by the A/B. Elektrometall[1] showing the amount of coke, (or charcoal), and the electrical energy required to produce one ton of pig-iron from a specified ore, as affected by the percentage of CO_2 in the furnace gases. The tables show that with increasing percentages of CO_2 the consumption of both coke and electrical energy decreases.

The records of the experiments at Trollhättan show a very wide variation in the percentage of CO_2 in the gases, which run from about 8 to 35 per cent, depending on the kind of ore and flux, as well as on the speed of the gas-circulation; but there is very little information in regard to the amount of CO_2 in the absence of any circulation. In the later work the tendency at Trollhättan has apparently been to moderate the speed of the gas-circulation; getting, over long periods, less than 20 per cent of CO_2 in the escaping gases.

It appeared that the effect of the circulation could be gathered from a comparison of two cases, in which, using the same ore, etc., the CO_2 was 10 per cent without circulation, and 25 per cent with circulation. The writer has made such a calculation -- simplified as far as possible, but retaining all factors essential for making a fair comparison between the cases. The results are given on pages 24 to 27 and they show that the circulation of the gases causes a considerable saving, which amounts (per ton of iron) to 35·2 Kg. of coke (11 per cent of the whole) and 152 K.W. hours (7 per cent of the whole); but that the escaping gas, in that case, is poorer in heating power by 340,000 Cals. (23 per cent of the whole). The heat-value of the coke, and the effective heating power of the electrical energy saved, are together equal to the decrease in heating power of the gas.

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[1] See page 28

Collecting the results of all the calculations, it appears:—(1) that without circulation, the escaping gases have a heat-value about equal to the net heat-requirements of the furnace; (2) that with the gas-circulation, about one-fourth the value of the escaping gas is utilized in the furnace, thus saving about 11 per cent of the coke, and 7 per cent of the electrical energy.

Thus we see that if the escaping gases could be perfectly utilized, the furnace could be run with a small fraction of the power that is needed at present, and that the circulating system only effects about one-fourth of the large saving that is theoretically possible.

If, instead of the present shaft, and circulation of gases, we used some system in which the gases were burnt, and used to heat the ore and flux, (either before or after the admixture of the fuel), it might be possible to effect a greater economy than at present; but such a system would not have a very high efficiency—perhaps 50 per cent at the most—would be complicated and bulky, and would consume the whole of the gases.

Another alternative would be to discard the gas-circulation, and to consider the gases as a by-product, to be used in heating open-hearth furnaces for turning the pig-iron into steel. In this way the efficiency of the smelting furnace itself would appear to be lower, but the whole efficiency would have been raised. The gas produced in making a ton of pig-iron in the electric furnace would almost suffice for the production of one ton of steel in the open-hearth furnace.

If the escaping gases can be economically utilized in this manner, it will be allowable to dispense with the gas circulating system, and with the whole or part of the stack, if these changes are considered desirable in the interest of simplicity and cheapness of construction, or in order to increase the size and capacity of the smelting chamber.

These conclusions may be summarized as follows: (1) the large stack and circulating system does increase the efficiency of the smelting furnace, but scarcely to an extent that is commensurate with the complication and expense entailed; (2) if the gases from the furnace are utilized for steel-making, the saving effected by the present system becomes even less apparent; (3) the large stack of the present furnace probably constitutes a serious hindrance, when it is desired to materially increase the size of the unit, so as to produce say 100 tons of pig-iron, daily, instead of 20 or 30; and (4) if a furnace of such capacity can be successfully operated, the thermal economies that accompany an increase in scale will probably over-balance any losses incurred by the loss of the present shaft.

In drawing these conclusions it must be remembered that the Elektrometall furnace has demonstrated its efficiency in commercial operation in Sweden; while the Helfenstein furnace is still in the experimental stages. In California, however, where a foundry iron must be produced, a simple smelting furnace without a shaft has been found to be the best.

HEAT DISTRIBUTION IN TROLLHÄTTAN FURNACE.

CALCULATIONS BY MESSRS. LEFFLER AND NYSTRÖM.

Series 1. Charges 1-10. November 16, 1910-February 11, 1911.

Ore mainly Tuolluvaara magnetite. 63·5% Fe.
Pig-iron Open-hearth 13·1 tons daily.

Fe	96·41%	Si	0·34%	S	0·012%
C	3·57%	Mn	0·44%	P	0·019%

Electrical Supply

Phase I 13,731 amp. 65·2 volts.
" II 13,416 " 65·9 "

1319 Kilowatts

Working time 2009·9 hours.
Standing " 105·7 "
Total " 2115·6 "

FOR ONE TON OF PIG-IRON.

Supplies.	
1525	Kg. ore.
85·3	Kg. raw limestone.
415·70	Kg. charcoal.
0·45	Kg. coke.
6·76	Kg. electrodes
2296	Kilowatt hours

By Products.

190·7 Kg. slag.

733·64 Kg. dry gases at 60°C

CO_2	10·96%	CH_4	2·48%
CO	79·59%	H	6·97%

HEAT DISTRIBUTION.

Reduction of Fe, Si, etc.....	1,640,786	Cals.			
Oxidation of carbon..........	908,830	„			
Net reduction of Fe etc. by C.	731,956	„			=37·4%
Melting pig-iron....	302,400	„			18·5 „
Melting slag..........	100,000	„			5·8 „
Decomposing carbonates....	49,134	„			2·5 „
Evaporation of water......	53,179	„			2·7 „
Sensible heat in gases......	9,463	„			0·5 „
Total heat utilized	1,246,132	„	=1454	K.W. hrs. =	63·33 „
Loss in transformers........................			42	„	1·83 „
„ „ low tension conductors..........			76	„	3·31 „
„ „ water cooling..................			150	„	6·53 „
„ „ radiation etc. (by difference).....			574	„	25·00 „
Kilowatt hours supplied..............			2296	„	100·00 „
Potential energy in gases 1,672,000 Cals... ..			=1944	„	84·6 „

Series 2. Charges 30-41. April 9-May 18, 1911.

Ore about 5 parts magnetite to 3 parts hematite. 55·9% Fe.
Pig-iron Open-hearth 15·1 tons daily.

Fe	95·35%	Si	1·00%	S	0·020%
C	3·52%	Mn	0·89%	P	0·013%

Electrical Supply.

Phase I	13,564 amps.	75 volts	Working time		851·7 hours.
„ II	11,817 „	83 „	Standing	„	68·3 „
1717 Kilowatts			Total	„	920·0 „

FOR ONE TON OF PIG-IRON.

Supplies.
1725·7 Kg. ore
48·5 Kg. raw limestone
92·5 Kg. burnt lime
396·7 Kg. charcoal
4·99 Kg. electrodes.
2481 Kilowatt hours.

By Products.
455 Kg. slag.
738 Kg. dry gases at 64°C.

CO_2	8·77%	CH_4	3·18%
CO	81·57%	H	6·48%

HEAT DISTRIBUTION

Reduction of Fe, Si, etc.	1,722,155	Cals.			
Oxidation of carbon	882,863	„			
Net reduction Fe etc. by C	839,292	„			=39·46%
Fusion of pig-iron	302,400	„			14·22 „
Fusion of slag	227,500	„			10·70 „
Decomposing limestone	27,391	„			1·29 „
Evaporating water	38,189	„			1·80 „
Sensible heat of gases	10,361	„			0·49 „
Total heat utilized	1,445,133	„	=1686	K.W. hrs.	= 67·96 „
Transformer losses			68	„	2·74 „
Losses in low tension conductors			95	„	3·83 „
„ „ cooling water			163	„	6·57 „
„ by radiation etc. (by difference)			469	„	18·90 „
Kilowatt hours supplied			2481	„	100·00 „
Potential energy in gases	1,623,000	Cals.	=1890	„	76·2 „

Series 3; Charges 30 and 31. April 9-April 20, 1911.

Part of series 2)

Ore roasted and containing about 1 part of Fe_3O_4 to 2 parts of Fe_2O_3, 52·2% Fe.

Pig-iron Open-hearth 17·26 tons daily.

Fe	94·62%	Si	1·14%	S	0·015%
C	3·68%	Mn	1·33%	P	0·012%

Electrical Supply

Phase I	11,922	amp.	81·9	volts
„ II	10,406	„	88·2	„

1680 Kilowatts

Working time		230·3	hours
Standing	„	9·8	„
Total	„	240·1	„

FOR ONE TON OF PIG-IRON.

Supplies

1478·5	Kg	roasted ore
303·4	„	ore briquettes
45·0	„	raw limestone
55·2	„	burnt lime
359·8	„	charcoal
4·99	„	electrodes
2241		Kilowatt hours

By Products

505 Kg slag
702·9 Kg dry gases at 74°C.

CO_2	20·72%	CH_4	3·40%
CO	68·97%	H	6·91%

HEAT DISTRIBUTION.

Reduction of Fe, Si, etc. to metal	1,768,874	Cals.		
Oxidation of carbon	1,004,246	„		
Reduction of Fe etc. by carbon	764 628	„		=39·79%
Fusion of pig-iron	302,400	„		15·77 „
„ „ slag	252,500	„		13·16 „
Decomposition of carbonates	22,911	„		1·20 „
Evaporation of water	12,423	„		0·65 „
Sensible heat in gases	11,643	„		0·60 „
Total heat utilized	1,366,505	„	=1595 K W hrs	=71·17%
Losses in transformers			61 „	2·72 „
„ „ low tension conductors			68 „	3·03 „
„ „ cooling water			146 „	6·53 „
„ „ radiation etc. (by difference)			371 „	16·55 „
Kilowatt hours supplied			2,241 „	100·00
Potential energy in gases	1,424,000	Cals.	=1,655 „	73·8

Series 4; Charge 45. September 3-October 1, 1911.

Ore nearly all magnetite (unroasted Tuolluvaara) Fe 64·8%.

Pig-iron Open-hearth 19·2 tons daily

Fe	95·58%	Si	0·36%	S	0·0036%
C	3·64%	Mn	0·40%	P	0·0181%

Electrical Supply

Phase I	10,012 amps.	78·7 volts	Working time	668·5 hours
„ II	9,729 „	82·9 „	Standing „	3·8 „
1407 Kilowatts			Total „	672·3 „

FOR ONE TON OF PIG-IRON.

Supplies		*By Products*
1,478·3 Kg.	ore	165 Kg. slag
59·7 „	raw limestone	663·7 Kg. dry gases at 62°C.
318·5 „	charcoal	CO_2 28·90% CH_4 1·69%
5·2 „	electrodes	CO 55·95% H 13·39%
1749	Kilowatt hours	N 0·07%

HEAT DISTRIBUTION.

Reduction of Fe, Si, etc. to metal	1,620,249 Cals.		
Oxidation of carbon	947,928 „		
Reduction of Fe, etc. by carbon	672,321 „		=44·82%
Fusion of pig-iron	300,000 „		20·04 „
„ „ slag	75,000 „		5·01 „
Decomposition of carbonates	34,757 „		2·32 „
Evaporation of water	24 283 „		1·62 „
Sensible heat in gases	8,711 „		0·58 „
Total heat utilized	1,115,072 „	=1,301K.W. hrs.	=74·39%
Losses in transformers		49·0 „	2·80 „
„ „ low tension conductors		51·0 „	2·90 „
„ „ cooling water		226·2 „	12·94 „
„ „ circulating gases		17·8 „	1·02 „
„ „ radiation etc. (by differen		104·0 „	5·95 „
Kilowatt hours supplied		1,749·0 „	100·00 „
Potential energy in gases 1,127,700 Cals.		=1,312 „	75·00 „

HEAT DISTRIBUTION IN TROLLHÄTTAN FURNACE.

CALCULATED BY A. STANSFIELD.

Charges 68 and 69. April 5-19, 1912.

Ore mainly magnetite. 52·0% Fe.

Pig-iron Bessemer 16·4 tons daily

Fe	94·24%	Si	0·76 %	S	0·0197%
C	3·52%	Mn	1·436%	P	0·0218%

Electrical Supply.

Phase I	12,613 amp.	77·1 volts.	Working time	322·9 hours
„ II	12,135 „	77·8 „	Standing „	19·8 „
1665 Kilowatts				342·7 „

FOR ONE TON OF PIG-IRON

Supplies	*By-products*
1812 Kg. ore	450 Kg. slag
92 „ raw limestone	[illegible] gases at 12°C
369·5 „ charcoal	CO_2 29·2%, CH_4 0·9%,
4·13 „ electrodes	CO 66·9%, H 0·7%,
2445 Kilowatt hours	N 2·3%

HEAT DISTRIBUTION

Reduction of Fe, Si, etc	1,580,200 Cals				
Oxidation of carbon	759,000 „				
Net reduction of Fe etc by C	821,200	„	= 955	K.W hrs	= 39·1%
Fusion of pig-iron	300,000	„	349	„	14·3 „
„ „ slag	217,500	„	252	„	10·3 „
Decomposition of carbonates	151,500	„	176	„	7·2 „
Evaporation of water	25,050	„	29	„	1·2 „
Sensible heat in gases	6,050	„	[illegible]	„	0·3 „
Total heat utilized	1,521,300		= 1768	„	= 72·4 „
Loss in transformers			67	„	2·7 „
„ „ low tension conductors			73	„	3·0 „
„ „ water cooling			345	„	14·1 „
„ „ circulating gases	9,070 Cals		= 11	„	0·4 „
„ „ radiation etc (by difference)			181	„	7·4 „
Kilowatt hours supplied			2445	„	100·0 „
Potential energy in gases	1,594,500		= 1855	„	75·9%

NOTES ON EFFICIENCY CALCULATIONS

(1) *Reduction of iron, etc.* In the Swedish calculations the heat required for the "reduction of the iron, silicon, etc.", corresponds to the dissociation of the oxides into metal and oxygen, as: $Fe_3O_4 = 3\ Fe + 2\ O_2$, and the heat of oxidation of the carbon by oxygen to CO and CO_2 is represented as a definite asset, just as in a blast-furnace, where the carbon is oxidized by the air-blast. In the author's opinion, a truer view of the case is given by combining these reactions, and calculating the heat of reduction of the iron etc., **by the carbon,** as in the equation $Fe_3\ O_4 + 3C = 3\ Fe + 2\ CO + CO_2$. The heat required for

this reduction varies, of course, with the proportion of CO to CO_2 in the resulting gases, but represents as a rule about 40 per cent of the heat value of the electrical supply.

(2) *Electrical efficiency.* The various items of heat required by the furnace have been grouped by the Swedish writers into necessary items on the one hand, and losses on the other hand; the sum of the necessary items divided by the whole representing the electrical efficiency. The division adopted appears to be correct, except in the case of the sensible heat of the furnace gases. This is an item that can be varied by differences in the furnace design, or operation, and this item should, therefore, stand amongst the losses.

(3) *Cooling water losses.* This large element of loss consists of two parts: (1) the cooling of electrodes by water-cooled contacts and collars; and (2) the water-cooling of other parts of the furnace. The water-cooling of electrodes appears to be an unavoidable element of loss, and Carl Hering has shown how the loss can be reduced to a minimum. Under the conditions in the Elektrometall furnace, a loss of about 7 per cent of the electrical supply appears to be inevitable. The actual loss from this source is about 10 per cent and the remaining 3 per cent or 4 per cent (in the later calculations) represents water-cooling of the furnace itself.

(4) The charges (68 and 69) selected for calculation by the author, correspond with a somewhat higher electrical consumption (2,445 K.W. hours) than was usual about that period. This selection was made, however, because the conditions remained constant in this case for a reasonable period, and because the iron obtained represented more nearly than in other cases the grade of iron that would be required in Canada.

EFFECT OF THE GAS CIRCULATION ON THE ECONOMY OF THE ELEKTROMETALL FURNACE.

A calculation of the amount of electrical energy and of fuel required for one ton of pig-iron (a) without, and (b) with, the circulation of the furnace gases.

Assumptions:—

1. (1) The ore is a magnetite containing 60 per cent of iron.
2. (2) The fuel is coke containing 85 per cent of fixed carbon and 15 per cent of ash.
3. (3) The flux is burnt lime and is equal in amount to one-fourth of the gangue from the ore, and one-fourth of the ash from the coke.
4. (4) The pig-iron contains 96·6 per cent iron, and 3·4 per cent carbon.
5. (5) The electrical efficiency of the furnace is 78 per cent.
6. (6) The furnace gases are by volume:—
    - (a) Without circulation, 10 per cent CO_2, 90 per cent CO;
    - (b) With circulation, 25 per cent CO_2, 75 per cent CO.

General. 1000 Kg. pig-iron contain 34 Kg. carbon, and 966 Kg. iron. This requires 1610 Kg. of magnetite.

1610 Kg. magnetite contains:	966 Kg. iron.
	368 Kg. oxygen (combined with iron),
	276 Kg. gangue
	1610

(a) Without circulation: gases contain 10 per cent CO_2, 90 per cent CO.

The CO_2 in gases contains	66·9	Kg. oxygen and	25·1	Kg. carbon.
" CO " " "	301·1	" " "	225·8	" "
	368·0	" " "	250·9	" "
Entering pig-iron			34·0	" "
Total carbon needed			284·9	" "

Coke for reduction (85 % carbon)	= 295	Kg
" " carburization	= 40	"
Total coke containing 50 Kg. of ash	= 335	
Gangue from ore, and coke ash	= 326	"
Burnt lime (one-fourth of this)	= 81	"
Total slag	407	"

HEAT REQUIREMENTS.

966 Kg. Fe from Fe_3O_4	= 1,557,100	Cals.	
25·1 Kg. carbon to CO_2	203,300	„	
225·8 Kg. carbon to CO	548,694	„	
Oxidation of carbon	751,994	„	
Net reduction of iron by carbon	805,106	„	
Fusion of 1000 Kg. pig-iron	300,000	„	
Fusion of 407 Kg. slag	203,500	„	
Evaporation of moisture, and sensible heat of gases; assume	35,000	„	
	1,343,606	„	= 1562 K.W. hrs.
This requires (at 78% efficiency)			2002 „

Calorific power of escaping gas....... = 1,280,286 Cals.

(b) *With circulation: gases contain 25 per cent CO_2, 75 per cent CO.*

The CO_2 in gases contains:	147·2 Kg. oxygen and	55·2	Kg. carbon.
„ CO „ „ „	220·8 „ „ „	165·6	„ „
	368·0 „ „	220·8	„ „
Entering pig-iron		34·0	„ „
Total carbon needed		254·8	„ „

Coke for reduction (85% carbon)	259·8	Kg.
Coke for carburization	40·0	„
Total coke containing 45 Kg. of ash	299·8	„
Gangue from ore, and coke ash	321	„
Burnt lime (one-fourth of this)	80	„
Total slag	401	„

HEAT REQUIREMENTS.

966 Kg. Fe from Fe_3O_4	1,557,100 Cals.	
55·2 Kg. carbon to CO_2	447,120 „	
165·6 Kg. carbon to CO	402,408 „	
Oxidation of carbon	849,528 „	
Net reduction of iron by carbon	707,572 „	
Fusion of 1000 Kg. pig-iron	300,000 „	
Fusion of 401 Kg. slag	200,500 „	
Evaporation of moisture, and sensible heat in gases; assume	35,000 „	
	1,243,072 „	= 1446 K.W. hrs.
This requires (at 78% efficiency)		1853 „
Calorific power of escaping gas =	938,952 Cals.	

(*c*) *Comparison of the two cases.*

	10% gas.	*25% gas.*	*Difference.*
Coke	335 Kg.	299·8 Kg.	35·2 Kg.
Power	2002 K.W. hrs.	1853 K.W. hrs.	149 K.W. hrs.
Gas	1,280,286 Cals.	938,952 Cals.	341,334 Cals.

This shows that the circulation of the gases, raising the CO_2 from 10 % to 25% will save 35·2 Kg. of coke and 149 Kilowatt hours per ton of iron made, but that the furnace gases will be poorer in heating power to the extent of 341,334 Cals. The saving of coke and electrical energy is made at the expense of the heating power of the furnace gases.

The circulation of the gases has enabled about one-fourth of their potential heating power to be utilized in the furnace; thus effecting an equivalent saving of coke and electrical energy.

(d) The figures published by the A/B. Elektrometall for the same assumed conditions of ore, coke and efficiency are:—

	10% gas.	*25% gas.*	*Difference.*
Coke	332 Kg.	294 Kg.	38 Kg.
Power	2020 K.W. hours	1875 K.W. hours	145 K.W. hours

The effect of varying proportions of CO_2 in the furnace gases on the consumption of coke and of electrical energy is shown in the following tables:—

Figures published by the A/B. Elektrometall.

TABLE I.

Consumption of Coke.

Ore assumed to be Fe_3O_4.
Coke " " hold 85%C.
Pig-iron " " 3·4% C.

Kg. coke per ton iron.

CO_2 in furnace gas	0%	5%	10%	15%	20%	25%	30%	35%
Coke for reduction	325	308	292	279	266	254	244	234
Coke for combined carbon......	40	40	40	40	40	40	40	40
Total.......	365	348	332	319	306	294	284	274

For the reduction of hematite ore the coke consumption is 12·5% higher.

TABLE II.

Consumption of Power.

Electric efficiency of plant 78%.

CO_2 in furnace gas	0%		10%		20%		30%	
% Fe. in charge	KWH per ton iron	Tons iron per H.P. Year	KWH per ton iron	Tons iron per H.P. Year	KWH per ton iron	Tons iron per H.P. Year	KWH per ton iron	Tons iron per H.P. Year
65%	2,056	3·13	1,926	3·35	1,826	3·54	1,739	3·71
60%	2,150	3·00	2,020	3·19	1,920	3·36	1,833	3·52
50%	2,390	2·72	2,260	2·85	2,160	2·98	2,073	3·11
45%	2,550	2·53	2,420	2·66	2,320	2·78	2,233	2·89

When unburnt limestone is used the coke and power consumption will be somewhat higher than shown in the above tables.

PART II.

CONDENSED REPORT UNDER SPECIFIC HEADS.

THE LOCALITIES WHERE ELECTRIC SMELTING FURNACES ARE IN COMMERCIAL OPERATION, OR IN PROCESS OF CONSTRUCTION.

The furnaces in commercial operation in Sweden are mostly of the "Elektrometall" type. Such furnaces are smelting iron ores and concentrates with charcoal at Domnarfvet, Hagfors, and Trollhättan. Additional furnaces of this type are in course of construction at Hagfors and Söderfors. An iron-smelting furnace of a modified Helfenstein type is in experimental operation at Domnarfvet. At Notodden and at Ulefos, in Norway, furnaces of the "Tinfos" type are in commercial operation, smelting iron ores with coke.

The number, style, and capacity of the furnaces is shown in the following list:—

THE NUMBER, STYLE, AND CAPACITY OF FURNACES.

1. At *Domnarfvet,* the Stora Kopparbergs Bergslags, A/B. have one Elektrometall furnace of 4,000 h.p. in commercial operation, producing about 30 tons of charcoal iron daily. They have also in experimental operation a modified Helfenstein furnace of 5,000 h.p. or more: particulars of which are not available, at present.

2. At *Söderfors,* the same Company have one Elektrometall furnace of 6,000 h.p. in course of construction.

3. At *Hagfors,* the Uddeholms Aktiebolag have three Elektrometall furnaces, each of 3,000 h.p., in commercial operation, each producing about 20-25 tons of charcoal iron daily. Two more Elektrometall furnaces of 4,000 to 5,000 h.p. each are to be built, and one of these is in course of construction.

4. At *Trollhättan*, one Elektrometall furnace of 3,000 h.p. is being operated commercially by the Strömsnäs Jernverks A/B. and produces about 22 tons of charcoal iron daily.

5. At *Notodden*, (Norway) the Tinfos Jernverk A/S has four furnaces ("Tinfos system") of 1600 h.p. each. Two[1] of these are in commercial operation using coke (instead of charcoal) and producing each about 10 tons of iron daily from a low grade ore. A smaller furnace of the same type is operated by M. Cappelen at Ulefos.

Mr. J. O. Böving, of the Electro-Metals Ltd., writing under date of June 4, 1915, gives the following list of furnaces in operation or construction in Sweden. I have numbered his list for easy comparison with the above.

1. At *Domnarfvet*, two furnaces of 3,000 h.p., and one of 6,000 h.p., in operation.

2. At *Söderfors*, three furnaces of 3,000 h.p., (building?).

2a. At *Ljusne*, one furnace of 3,000 h.p. (building?).

3. At *Hagfors*, three furnaces of 3,400 h.p. in operation, and three more building.

3a. At *Nykroppa*, two furnaces of 3,400 h.p., building.

4. At *Trolhättan*, one furnace of 2,000 h.p., in operation, and one of 3,000 h.p., building.

5. At *Notodden*, I understand, from another source, that three of the four furnaces have been in regular operation.

6. In the far north of Sweden, a large iron works, of 25,000 h.p., is to be constructed immediately.

THE NATURE AND ANALYSIS OF ORE AND PRODUCT.

1. At *Domnarfvet*, the phosphoric hematite Skärning ore from Grängesberg is smelted in the Elektrometall furnace, with charcoal and fluxes, producing a phosphoric pig-iron.

The ore contains 60% of iron, 5% of silica, 1% of phosphorus and traces of sulphur.

The pig-iron contains 0·5–1·0% of silicon, 1% of manganese, 2% of phosphorus, 0·010% of sulphur, and 3·6–3·8% of carbon.

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[1] Usually three are in operation at once

Bessemer slag is used in the charge to furnish manganese, and apatite to increase the amount of phosphorus in the pig-iron, which is converted into steel by the basic Bessemer process.

Non-phosphoric magnetite ores (about 50% iron in the charge) are smelted (at present in the Helfenstein furnace) with charcoal to make a high quality pig-iron. This is used in the acid open-hearth furnace to make a high quality steel for export.

2. At *Söderfors*, a specially high quality of iron has for a long time been made in charcoal blast-furnaces from the Dannemora ores; the Elektrometall furnace, now in course of construction, is intended for the production of this special quality of iron.

3. At *Hagfors*, open-hearth pig-iron was made containing 0·5% silicon, 0·4% manganese, 0·015% phosphorus, and 0·010% sulphur; and Bessemer iron containing 1·0—1·2% silicon, 2·5—3·0 % manganese, 0·018% phosphorus, and 0·005% to traces of sulphur.

A charge for open-hearth iron consisted of:—

38%	Finnmossen ore
28%	Taberg ore
20%	Tuolluvaara ore
4%	Långban ore
10%	Nordmark ore
100	10% limestone

This ore mixture (without the limestone) would contain about 57% of iron, 0·03% of sulphur, and 0·007% of phosphorus. The whole charge would contain about 52% of iron.

4. At *Trollhättan*, a usual charge consists of:—,

50%	Tuolluvaara ore
34%	Lerbergs ore
16%	Lerbergs concentrate
100	8% limestone

The ore mixture (without the limestone) would contain about 63% iron, 0·010% sulphur, and 0·015% phosphorus; and the whole charge about 58% of iron.

The pig-iron, which is intended for steel-making by the acid open-hearth process, contains: 0·05—1% silicon (usually about 0·3%), 0·15—0·20% manganese, 0·005—0·015% sulphur, and 0·020% phosphorus.

The present charge[1] consists of 50% Tuolluvaara ore, 30% Lerbergs ore, and 20% Lerbergs concentrates, with 9½% of limestone. The concentrates and powdery ore amount to about 40% of the charge.

5. At *Notodden*, iron ores are smelted which contain about 44% of iron, 0·025% of sulphur, and 0·022—0·040% of phosphorus. Coke is used, containing 1·2% of sulphur and 0·02% of phosphorus. White pig-iron from these materials contains about 0·4% silicon, 0·03% sulphur, and 0·06% of phosphorus. Grey pig-iron contains 2·0% silicon, 0·02% sulphur, and 0·065% phosphorus; with a larger proportion of limestone the sulphur can be further reduced, the iron containing 1·0—1·5% silicon, 0·08% phosphorus, and 0·01% to traces of sulphur.

THE COST OF THE ORE.

The operating companies are not prepared to publish exact figures for the cost of the ore, but Kr. 15 or $4.00 may be taken in a general way to represent the cost per ton of the Swedish ores delivered to the smelting plants.

THE CONSUMPTION AND PRICE OF ELECTRIC ENERGY, CHARCOAL OR OTHER FUEL, FLUXES AND ELECTRODES.

1. At *Domnarfvet*, making basic bessemer iron from phosphoric ores (60% iron) in the 4,000 h.p. Elektrometall furnace, requires 2,245 K.W. hours of electrical energy, costing in effect about 0·6 öre (0·16 cents) per K.W. hour; 23·6 hectolitres of charcoal, costing about 60 öre (16 cents) per Hl; 52 Kg. of bessemer slag; 30 Kg. of apatite; and 7·0 Kg. of electrodes, costing 35 öre (9 cents) per Kg.; for each ton of pig-iron.

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[1] The amount of concentrate is now increased to 27% without trouble in the furnace.

Pig-iron for use in the acid open-hearth furnace, smelted from ores containing only 50% of iron on the charge, requires 2,500 to 2,600 K.W. hours of electrical energy per ton of iron.

2. At *Hagfors*, one ton of acid open-hearth pig-iron made in a 3,000 h.p. Elektrometall furnace, from a charge containing about 52% of iron, requires 2,500 K.W. hours of electrical energy, 21 Hl. of charcoal, 180 Kg. of limestone and 6 Kg. of electrodes. The charcoal costs 75 öre (20 cents) per Hl.; the limestone Kr. 5, ($1.35) per ton and the electrodes 30 öre (8 cents) per Kg.

For making one ton of acid bessemer iron, 2,600—2,800 K.W. hours of electrical energy and 21 Hl. of charcoal are needed; the electrode consumption is about 8 Kg.

3. At *Trollhättan*, for making one ton of acid open-hearth pig-iron in the Elektrometall furnace, from a charge containing 58% of iron, there was required, during the year 1913, 2,116 K.W. hours of electrical energy, 23·95 Hl. of charcoal, 137 Kg. of limestone and 4.64 Kg. of electrodes.

4. At *Notodden*, in a 1,600 h.p. Tinfos furnace, one ton of white pig-iron, smelted with coke from a charge containing 44% of iron, requires 2,800 K.W. hours of electrical energy. One ton of grey pig-iron, from a charge containing 39% of iron, requires 3,000 K.W. hours of electrical energy.

The cost of electrical energy is a point of great importance in relation to the commercial operation of electric smelting furnaces, but such data are not always available for publication. The cost of power to the iron-smelting companies in Sweden may be taken in a general way to be from Kr. 25 to Kr. 45 ($7-$12) per h.p. year, or Kr. 33 to Kr. 60 ($9-$16) per K.W. year; such payment referring to the maximum amount that can be drawn from the high tension supply line.

THE NUMBER OF MEN EMPLOYED AND THEIR WAGES.

An electric smelting plant, consisting of one Elektrometall furnace as at Trollhättan, will need the services of some 25 or 30 men. This includes the foreman, the furnace men, the men employed in crushing and bringing up the ore and in bringing up the charcoal, men for removing the iron and slag and for load-ing and unloading; also the electrician, blacksmith, carpenter and watchmen. The wages average about Kr. 4 ($1.10) per day and will make a charge of nearly Kr. 6 ($1.60) per ton of iron.[1]

At *Hagfors*, three 3,000 h.p. furnaces are operated by 50 men who are paid about 42-44 öre (12 cents) per hour, working eight hours daily in most cases. This with bonuses and the higher wages of foremen will mean about Kr. 3 ($0.80) per ton of iron.

At *Domnarfvet*, where other furnaces are being operated, 16 men are assigned to the 4,000 h.p. furnace, the men working 12-hour shifts and making about Kr. 4.50 to Kr. 5.00 ($1.20—$1.35) a day. This is equivalent to about Kr. 3.00 ($0.80) per ton of iron.

THE COST OF PLANT AND UPKEEP.

The complete cost in Sweden of an electric smelting plant of three Elektrometall furnaces of 3,000—4,000 h.p. is estimated at Kr. 300,000, ($80,000) per furnace.

The cost of repairs and upkeep depends largely on the need for rebuilding the crucible and arch of the furnace and relining the shaft, and this depends to some extent on the nature of the product, a furnace lining lasting far longer when making white iron than when grey iron is being made. An average charge of Kr. 12,000 ($3,250) per year for one furnace may be set down for repairs and upkeep.

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[1] The labour cost at Trollhättan includes all workmen required for an isolated plant. The costs given for the other plants only include the men necessary for the furnace operations (and does not include electrician, blacksmith, carpenter, and such men).

PART III.

DETAILED ACCOUNTS OF SOME ELECTRIC SMELTING PLANTS AND ELECTRIC STEEL-MAKING FURNACES IN SWEDEN AND NORWAY.

ELECTRIC SMELTING PLANT AT DOMNARFVET.

The electric smelting plant of the Stora Kopparbergs Bergslags A/B, at Domnarfvet, contains one Elektrometall furnace of 4,000 h.p., which has been in operation since November 1911; one modified Helfenstein furnace of 5,000 h.p. or more; and one Helfenstein ferro-silicon furnace of 7,000 h.p. It was at this plant that the Elektrometall furnace was originated, and the early furnaces have been fully described by Dr. Haanel.[1] The present Elektrometall furnace was built after the 3,000 h.p. furnace at Trollhättan and embodies the experience gained with that furnace. On account of its large size the furnace at Domnarfvet is provided with six electrodes and utilizes three-phase current.

A report follows of the operation of this furnace from July 22, 1913, until the time of my visit in June, 1914.

Report on the 4,000 h.p. Elektrometall Furnace at Domnarfvet from 7 p.m., July 22, 1913, to noon, June [illegible]

	hours	*days*
Total time	8153	339·7
Time of operation	7542	314·2
Holidays (Christmas and Midsummer)	239	10·0
Other lost time	372	5·5
Total lost time	611	25·5

Lost time as percentage of whole 7·5%

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[1] Dr. Eugene Haanel: "Report on the investigation of an Electrical Shaft Furnace. Domnarfvet, Sweden." Ottawa, 1909.

Dr. Eugene Haanel: "Recent advances in the construction of Electric Furnaces for the production of Pig Iron, Steel, and Zinc." Ottawa, 1910.

MATERIALS SMELTED.

	Total	*Per ton pig-iron.*
Skärning ore	13,597,550 *Kg.*	1,516 *Kg.*
Bessemer slag	462,440 "	52 "
Apatite	272,640 "	30 "
	14,332,630 "	1,598 "

Charcoal 23,345 charges of 9 hectolitres	210,105 Hl.	23·6 Hl.
" at 15 Kg. per Hl	3,151,575 Kg.	351 Kg.
Electrodes, gross	61,950 Kg.	6·91 Kg.
Electric energy	20,138,000 K.W.hrs.	2,245 K.W.hrs.

Average load during working time..........2670 K.W. =92% full load.
" " " whole time..............2470 " =85% " "
(Full load taken as 2,900 K.W.=3940 E.H.P.)

Thomas pig-iron produced	8,968,000 Kg.
" " per working day	28·5 tons.
" " per total day	26·4 "
" " per h.p. year utilized	2·87 "
" " " " " paid for	2·44 "

(8,968 tons in 339·7 days using.....3,940 h.p.)

ANALYSIS OF CHARGE AND PRODUCT.

Skärning ore from Grängesberg.

Fe_2O_3	86%
(Fe	60%)
P	1%
SiO_2	5%

Bessemer Slag.

Mn O	30%
Si O_2	50%
FeO, CaO, Al_2O_3	20%

Apatite.

Fe	30%
P	6%

Thom · Pig-iron.

P	2%
Mn	1%
Si	0·5–1·0%
S	0·010%
C	3·6–3·7%
Fe (by difference)	92·6%

Charcoal.

Moisture	10–14%
Fixed carbon	60–70%
Volatile matter	20–25%
Ash	0·5%

ELECTRIC FURNACES AT HAGFORS.

The Uddeholms Company have in operation in their plant at Hagfors, three Elektrometall furnaces,[1] nominally of 3,000 h.p., but capable of consuming about 3,400 h.p. each. This constitutes the largest electric smelting plant for iron ores in any part of the world. The plant is to be increased by the addition of two more furnaces of 4,000 to 5,000 h.p., one of these being in process of construction. Electric power is obtained from the Company's own power station at Forshultforsen, 9½ miles away, with a capacity of 21,000 h.p.; and another power station, Malta-forsen, of 4,000 h.p. Two additional plants of 4,000 h.p. each, are in course of construction, making a total of 33,000 h.p. The power is transmitted as three-phase current of 25 cycles, at a voltage of 12,000, and is stepped down by transformers at the furnace to about 80 volts; the possible range being from 50 to 100 volts.

Each furnace has six cylindrical electrodes, which are connected to the low voltage terminals of three transformers of 1,000 K.V.A. capacity, each transformer being connected to a pair of electrodes situated on one diameter of the furnace. The high tension terminals of the transformers are connected in delta to the three-phase supply, and the connexions can be altered by nine steps for each high tension winding, so that the voltage supplied to each pair of electrodes can be varied at will between 50 and 100 volts, independently of the voltage of each of the other two pairs of electrodes. The power factor, (Cos.ϕ) is found to be 0·95 to 0·97. The electric plant is protected by suitable lightning arresters, and provision is made for replacing, by a fresh one, any transformer that might become defective.

The three furnaces, shown in Plates III, IV, V, and VI, are contained in one building, which is divided into three bays: one bay being for the transformers and electrical instruments, one for the furnaces, and one for the casting and removal of pig and slag. The electrical apparatus is separated from the furnaces by a dividing wall.

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[1] The first furnaces were constructed by the Elektrometall Company, but No. 3 and No 4 furnaces have been built by the Uddeholms Company after designs by their own engineer, Mr. Edvin Fornander and have been modified in several important particulars from the original designs.

The molten iron can be cast in open iron pig-moulds, or removed in ladles to the open-hearth furnaces or Bessemer converters. The slag is poured into moulds, and has been used for building stones. The slag and iron are tapped from the same opening in the furnace, and are separated by a skimmer.

Pig-iron produced in the furnaces for use in the acid open-hearth contains:—

Silicon..........0·5%   Phosphorus. ...0·015%
Manganese.....0·4%   Sulphur.........0·010%

It is partly grey, and partly white, in the fracture. An ore charge for making this iron consists of:—

38%	Finnmossen ore
28%	Taberg ore
20%	Tuolluvaara ore
4%	Långban ore
10%	Nordmark ore
100	10% limestone

This charge contains about 52% of iron, and to make one ton of the pig-iron needs 2,200—2,500 K.W. hours, and 21 hectolitres, or 47 (heaped) bushels of charcoal made from pine and fir wood. The consumption of electrodes is about 6 Kg. per ton of iron.

Pig-iron for use in the Bessemer converter contains:—

Silicon..........1·0—1·2%
Manganese.....3·0—2·5%
Phosphorus.....0·018%
Sulphur.........0·005% to trace.

The ore-charge for this iron is a little different from the previous charge, and includes some manganiferous ores, to furnish the necessary manganese. The charcoal used is 21 hectolitres, or 47 (heaped) bushels per ton of pig-iron, and the electric energy amounts to 2,600—2,800 K.W. hours per ton. The electrode consumption is about 8 kilograms per ton of iron.

The usual daily output per furnace is about 23 tons of open-hearth iron, or 20 tons of Bessemer iron.

The circulation of the gases in the Elektrometall furnaces is very important in view of fuel economy, as it causes the escaping gases to contain a larger percentage of CO_2. This has the further effect of increasing the consumption of the electrodes, but this is less important financially than the saving in fuel. Thus at Hagfors, with a rapid circulation of gases, which consequently contain as much as 21%–26% of CO_2, the charcoal consumption is 21–22 hectolitres, and the electrodes loss is 6 Kg. At Trollhättan with a similar charge, but less active circulation, and lower percentage of CO_2, the fuel consumption is from 24–25 hectolitres of charcoal, and the electrode consumption is only 3 Kg. per ton. The difference of 3 hectolitres of charcoal means a saving of Kr. 2·25 (60 cents) per ton, caused by the more rapid circulation; while the difference of 3 Kg. of electrodes means a loss of 90 öre (24 cents). On the other hand, the more rapid circulation will cost more to maintain, and will be more difficult with powdery ores, and the gas from the furnace will be of less value for use in open-hearth or other furnaces.

The gas at Hagfors has a calorific power of about 2,300 Cal. per cubic metre, and is used in the open-hearth furnaces. Its value is about Kr. 3 to Kr. 3·50, (about 90 cents), per ton of pig-iron.

The labour at Hagfors is usually arranged in three shifts of six hours each. That is each shift of men work for six hours and rest for twelve hours. The following are needed for operating the three furnaces:—

		Total Number
6	for tapping, per 6 hour shift, at 44 öre per hour	18
3	" furnace top, per 6 hour shift, at 44 öre per hour.	9
2	" charcoal house, per 6 hour shift, at 42 öre per hour and 1 extra by day.	7
4	" crushing, per 8 hour shift, at 42 öre per hour.	8
1	" foreman, per 6 hour shift, at Kr. 140 per month.	3
		45

In regard to the repairs necessary for these furnaces, one has been in operation for 1½ years, and may last for 2 or 3 years, but a new arch for the crucible is needed after about 8 months.

ELECTRIC SMELTING FURNACE AT TROLLHÄTTAN.

After the successful experimental work at the Domnarfvet works, during the years 1909 and 1910, the Association of Swedish Ironmasters, "Jernkontoret", constructed a furnace of 2,500—3,000 h.p. at Trollhättan.

This furnace was started in November 1910, and was operated for experimental tests during the years 1911 and 1912; details of these tests are given in the reports of J. A. Leffler and others, in the years 1911 and 1913. On the conclusion of these tests the furnace was taken over by the Strömsnäs Jernverks A/B and has been operated commercially by them since October 1912. Views of this furnace are given in Plates I and II.

A detailed report for the year 1913 is appended.

Report of the 3,000 h.p. Elektrometall Furnace at Trollhättan, for the year 1913.

MATERIALS SMELTED.

	Kilograms	*Kg. per ton of iron*
Kiruna A ore	1,023,080	
Tuolluvaara ore	4,738,855	
Lerbergs "	3,564,255	
Persbergs "	47,970	
Tabergs "	7,820	
Lump "	9,381,980	1,279
Lerbergs concentrate	2,041,985	
Persbergs "	140,590	
Concentrate, 19% of ore	2,182,575	299
Total ore	11,564,555	1,578
Limestone, 8·6% of ore	1,001,155	136
Total burden	12,565,710	1,714

	Total	*Per ton of iron*
Charcoal, 27,019 charges of 6·5 Hl.	175,623 Hl.	23·95 Hl.
„ if 1 Hl. = 15 Kg.	2,634,355 Kg.	359·2 Kg.
(Total burden per hectolitre of charcoal..71·55 Kg.)		
Electrode consumption, gross	34,039 Kg.	4·64 Kg
„ „ net	30,366 Kg.	4·14 Kg.
(More recent figures are about 3 Kg. per ton, gross or net.)		

ELECTRIC POWER CONSUMPTION.

Time of operation	7970·6 hours.	91% of whole
„ „ stoppages	789·4 „	9% „
Total time	8760 „	
Kilowatt hours, including motors and lights	Total	15,838,250
	Per ton of iron	2,160
K.W. hours for furnace alone, per ton of iron		2,116

		% of 2,200
Average load while working, whole plant	1,990 K.W.	90·5
„ „ „ „ furnace only	1,945 „	88·4
„ „ over whole time, whole plant	1,808 „	82·2
„ „ „ „ „ furnace only	1,770 „	80·4

The combined capacity of the transformers is 2,200 K.W., or 3,000 h.p.

Each electrode is usually loaded with 500 K.W. or 2,000 K.W., for the whole furnace.

OUTPUT OF PIG-IRON.

Total output, 1,511 tappings, 7,333,995 Kg.
„ „ 63·42% of the ore; 58·36% of the burden.
Daily output, for the whole time, 20·08 tons.
„ „ for working time, 22·05 tons.
Output per h.p. year (power used for whole plant) 2·98 tons.
„ „ „ („ „ „ furnace only) 3·05 tons.
Output per h.p. year (power paid for, for whole plant) = 7,334 ÷ 3,000 = 2·44 tons.
The iron contains:—Silicon 0·05—1·0% (usually 0·3%);
Manganese 0·15—0·20%; Sulphur 0·005—0·015%; Phosphorus 0·020%.

NOTE.—During the time covered by this report the furnace was allowed to cool, the hearth and roof were relined, and the furnace was reheated.

THE TINFOS ELECTRIC SMELTING FURNACE.

The Tinfos Jernverk A/S have a plant at Notodden, Norway, for the electrothermic smelting of iron ores.

The furnace in use is the "Tinfos" furnace, and resembles the "Old Tinfos furnace" figured by Paul Nicou. It is often described as the Bie Lorentzen furnace, but this is incorrect, as the furnace now in use does not possess the essential features of that invented by Hans Bie Lorentzen, which is also figured by Paul Nicou.

The furnace consists essentially of a long rectangular smelting chamber **A**, (Fig. 2) having one carbon electrode **B** embedded in the bottom and three square carbon electrodes entering through the top; one of them appearing at **C**. The ore mixture, consisting of ore, limestone and coke, enters the furnace through two rectangular chutes **d** and **e** which extend the whole length of the furnace. The roof of the furnace and of the chutes is supported by two hollow water-cooled beams, **F** and **G**, extending from end to end of the furnace. The pig-iron and slag are tapped from one end of the furnace.

The three movable electrodes **C** are all connected to the same pole of the electrical supply, and the bottom electrode **B** is connected to the other pole; thus single-phase current is employed. In order to utilize the three-phase supply, three furnaces are operated together. Each furnace employs about 1,600 E.H.P. at about 35—55 volts, 50 cycles.

It may be pointed out that the Tinfos furnace is substantially the same as the Haanel-Héroult furnace[1] which was illustrated in Dr. Haanel's Report in 1907 on the Experiments at Sault Ste. Marie. The upper electrode (or electrodes) enters vertically in the middle of either furnace and between two chutes which supply the ore charge; the opposing electrode being, in each case, situated in the bottom of the furnace. Both furnaces, also, use single-phase alternating current. The difference in construction between the two furnaces depends on the fact that the Haanel-Héroult furnace has only one upper electrode, and has consequently a nearly circular crucible or smelting chamber

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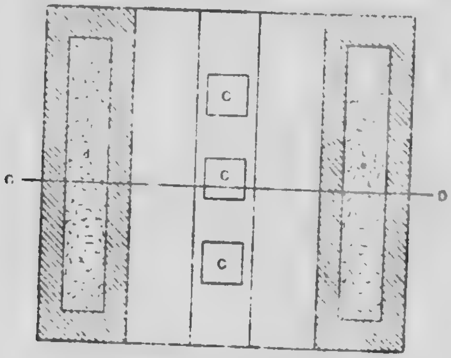
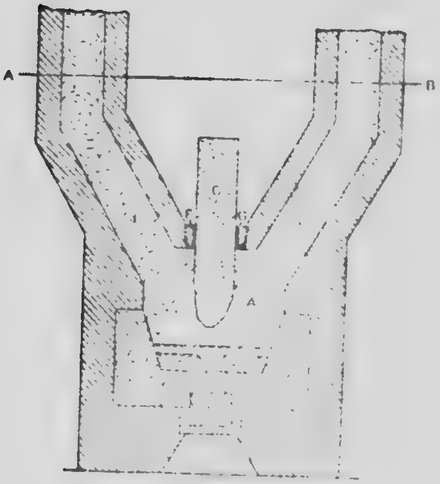
[1] Haanel-Héroult Electric Furnace:—"Report on the Experiments made at Sault Ste Marie, Ont., under Government auspices, in the smelting of Canadian iron ores by the Electro-Thermic Process," by Eugene Haanel, Ph. D., Ottawa, 1907, p. 92.

"The Electric Furnace, its construction, operation and uses," by Alfred Stansfield, D.Sc. New York 1914, p. 184



SECTIONAL PLAN ON A-B



SECTIONAL ELEVATION ON C-D

Fig. 2. The Tinfos furna

while the Tinfos furnace has three upper electrodes and a long rectangular smelting chamber. The length of this chamber has led to the use of the two water-cooled beams for supporting the roof of the Tinfos furnace, while in the Haanel-Héroult furnace the same purpose is served by a simple arch of brickwork.

The following particulars, showing the operation of the Tinfos furnace, have been condensed by the writer from a report published by the Tinfos Jernverk A/S.

ORES USED.

Grevinde Wedels Grube Langö.

Fe	44·20%	Al_2O_3	5·72 %
SiO_2	11·04 „	Mn	0·12 „
CaO	9·16 „	P	0·041 „
MgO	1·27 „	S	0·026 „

Fru Ankers Grube Langö.

Fe	44·30%	Al_2O_3	3·38 %
SiO_2	19·22 „	Mn	0·18 „
CaO	8·01 „	P	0·022 „
MgO	5·62 „	S	0·021 „

Coke.

Ash, 8·64%; S, 1·20%; P, 0·020%.

Limestone.

SiO_2	5·50%	$Al_2O_3 + Fe_2O_3$	1·20%
CaO	51·72 „	S	0·06 „

FURNACE NO. 3, MARCH, 12 to 14, 1913.

Product	White pig-iron; 2,800 K.W. hours per ton.	
Charge	Grevinde Wedels Grube	300 Kg.
	Fru Ankers Grube	100 „
	Coke	75 „

Record.

Date	*Tap*	*Kg.*	*C.*	*Si.*	*Mn.*	*P.*	*S.*
12–3–13	26	3310		0·47			0·038
	27	3250		0·36			·027
	28	3190		0·44	0·09	0·060	·014
13–3–13	29	2239	3·79				·028
	30	3209	3·27	0·39			·020
	31	2587	3·29	0·28			·034
14–3–13	32	3024	3·22	0·28	·10	0·065	·041
	33	2900		0·60			·025
	34	3020		0·68			·005
		26729					
		8910 daily					
		2970 per tap					

FURNACE NO. 3, MARCH, 17 to 20, 1914.

Product	Grey pig-iron 2,950 K.W. hours per ton.	
Charge	Fru Ankers Grube	400 Kg.
	Limestone	50 „
	Coke	70 „

Summarized Record.

Taps No. 300 to 308 gave 26,781 Kg. of pig, which is equal to 2,976 Kg. per tap. The average analysis was about:—

C, 3·15%; Si, 2·0%, Mn, 0·2%; P, 0·065%; S, 0·015—0·030%.

FURNACE NO. 3, APRIL 29, to MAY 4, 1914.

Product	Grey pig-iron 3,010 K.W. hours per ton.	
Charge	Grevinde Wedels Grube	200 Kg.
	Fru Ankers Grube	200 „
	Limestone	70 „
	Coke	76 „

Summarized Record.

Taps No. 815 to 826 gave 35,806 Kg. of pig, which is equal to 2,984 Kg. per tap. The average analysis was about:—

Si, 1·0—1·5%; Mn. 0·05—0·10%; P, 0·08%; S, tr. to 0·01%.

The Tinfos furnace differs from the Elektrometall furnace in having the electrodes placed in the middle, and the ore supplied laterally: an arrangement which appears to favour economy of heat. The fundamental difficulty of supporting the roof of such a furnace appears to have been met in a satisfactory manner.

In the Tinfos furnace the gases pass up the chutes, thus heating the ore charge to some extent, but no circulation is used, and the gases are not employed at present in any way outside the furnace. In a furnace of this type, like the Helfenstein furnace, it would be necessary to determine the value of the escaping gases for use outside the furnace, before its efficiency could be compared with that of the Elektrometall furnace, in which the gases are utilized to a greater extent within the furnace.

The furnace is interesting also, because coke is used instead of charcoal as a reducing reagent. For obtaining a large output of pig-iron of moderate quality, it will often happen that coke is preferable to charcoal, on account of its cheapness, and greater abundance. The Elektrometall furnace has, so far, not proved satisfactory when using coke, and this adds interest to any furnace in which coke can be employed.

The published analyses show that with coke containing 1·2% sulphur, white pig-iron was obtained having 0·03% sulphur, without the use of any limestone in the charge. When making grey pig-iron the sulphur was reduced to 0·02% and 0·01%, according to the amount of limestone employed. The management inform me that the sulphur can be kept down to traces—that is to say under 0·01%—but of course this increases the cost, as more limestone must be employed.

The data quoted above are not full enough to allow a satisfactory comparison to be made with the records of the Elektrometall furnaces, but this is of less consequence as the conditions are so different in the two cases. The Tinfos furnace uses poorer ores, coke instead of charcoal, and less total power, so that no useful comparison can be made.

The Tinfos furnace differs essentially from both the Elektrometall and the Helfenstein furnaces, in using single-phase instead of two or three-phase current. It follows from this, that all the electric current entering by the upper electrodes, must pass down through the charge into the molten metal, and out by the bottom electrode. In the other furnaces the current enters, and leaves by the upper electrodes, and no connexion need be made to the bottom of the furnace. Fear has been expressed that under the latter conditions the electric current may, in part at least, pass from one electrode to the other through the mass of unfused ore and fuel without passing into and through the molten iron in the bottom of the furnace, and that on this account the heat will be too much dissipated, and the temperature in the smelting zone may not be high enough for the elimination of sulphur, and for similar purposes. In a three-phase furnace the distribution of the electric current can probably be controlled by regulating the height of the electrodes, as the lower these are placed the more the electric current will pass from each other directly to the molten iron which forms the neutral point in the furnace. The single-phase furnace certainly avoids this difficulty altogether, but it is necessary to use three furnaces so as to employ the three-phase electric power. A further difficulty is met in attempting to equalize the current supplied to each of the upper electrodes, and it may be found desirable for each electrode to be supplied from a separate transformer having its own voltage regulator, in order to avoid the necessity of moving the electrodes up and down to obtain an equal distribution of current.

The single-phase furnace has also the disadvantage of using a decidedly lower voltage, and thus increasing the electrical losses in electrodes, cables, and transformers. In the Tinfos furnace, the lower voltage may be due in some measure to the use of coke instead of charcoal (as coke is a better electrical conductor), but apart from this a furnace using a bottom electrode will generally have a decidedly lower voltage than one using only movable electrodes connected in series.

As there is no coking coal in Norway, the Tinfos Jernverk have to import coke for use in their furnaces. At first, a good foundry coke was employed, but now they use a gas coke costing 21/– ($5.10) a ton, which they obtain from England.

APPROXIMATE ESTIMATE OF THE COST OF AN ELECTRIC SMELTING PLANT IN CANADA.

By Assar Grönwall.

1914.

Size of the plant: 3 electric furnaces of 4,000 H.P.

Excavation, levelling, railway tracks, store house for ore and coke, or charcoal, foundations for buildings and furnaces	$ 30,000
Buildings:—	
House of light iron-construction for 3 furnaces	60,000
Crusher plant house, laboratory, inclusive of appliances, workshop for repairs, and store house, and various smaller shops	12,000
Furnaces:—	
3 furnaces @ 4,000 H.P., with fans and gaspipes	75,000
Electric transformer instruments, with low tension conductors	100,000
Moulds, ladles, tools, and instruments	10,000
Travelling crane of 5 tons capacity	6,000
Ore crusher, apparatus for transporting crushed ore to the furnace top	7,000
Side tracks for transport, and other transporting devices	7,000
Water pipes, and waste pipes	5,000
Drawings, and supervision during construction, and unforeseen expenditures	48,000
	$360,000

Approximate Estimate for Production in Canada of 1000 kilograms (2204 lbs.) of pig-iron.

(a) ELECTRIC WHITE (CHARCOAL) PIG-IRON:—

1600 kilo ore	@$ 4/t	$6.40
100 » lime (Cao)	@» 15/t	1.50
340 » charcoal	@» 12/t	4.08
0·37 H.P.Y. (2400 K.W.H.)	@» 10/H.P.Y	3.70
6 kilo electrodes	@» 85/t	0.51
Labour and engineering		1.20
Office, and organization		0.50
Repairs		0.50
Depreciation (6% of $360,000 for yearly output.)		0.72
General expenses		0.50
Petty charges		0.39
		$20.00

(b) ELECTRIC GREY (CHARCOAL) PIG-IRON:—

1600 kilo ore	@ $ 4/t	$6.40
100 » lime (Cao)	@ » 15/t	1.50
370 » charcoal	@ » 12/t	4.44
0·40 H.P.Y. (2600 K.W.H.)	@ » 10/H.P.Y	4.00
8 kilo electrodes	@ » 85/t	0.68
Labour, and engineering		1.20
Office, and organization		0.50
Repairs		0.60
Depreciation (6% of $360,000 for yearly output.)		0.72
General expenses		0.50
Petty charges		0.46
		$21.00

(c) ELECTRIC WHITE (COKE) PIG-IRON:—

1600 kilo ore	@ $ 4/t	$6.40
120 » lime	@ » 15/t	1.80
370 » coke (85%C)	@ » 5/t	1.85
0·39 H.P.Y. (2500 K.W.H.)	@ » 10/H.P.Y	3.90
7 kilo electrodes	@ » 85/t	0.60
Labour, and engineering		1.20
Office, and organization		0.50
Repairs		0.50
Depreciation (6% of $360,000 for yearly output.)		0.72
General expenses		0.50
Petty charges		0.53
		$18.50

(d) ELECTRIC GREY (COKE) PIG-IRON:—

1600 kilo ore	@ $ 4/t.	$6.40
130 „ lime	@ „ 15/t.	1.95
400 „ coke	@ „ 5/t.	2.00
0·42 H.P.Y. (2700 K.W.H.)	@ „ 10/H.P.Y.	4.20
9 kilo electrodes	@ „ 85/t.	0.77
Labour, and engineering		1.20
Office, and organization		0.50
Repairs		0.60
Depreciation (6% of $360,000 for yearly output.)		0.72
General expenses		0.50
Petty charges		0.66
Exclusive of Royalty		$19.50

NOTES ON ESTIMATE OF COST.

Cost of Plant.

The Elektrometall furnace and its electrical and other equipment have been so fully described in various publications that the cost of establishing such a plant at any specified point in Canada can be satisfactorily estimated independently of the figures here given.

Cost of Production of Pig-iron.

(1) *General.* The estimates are for the production of one metric ton (2204 lbs.) of pig-iron, which is either "white", that is low in silicon and of the kind usually produced in the Swedish furnaces, or "grey", that is, high in silicon—presumably foundry or similar iron.

In cases (a) and (b) the fuel is charcoal, as is usual in Swedish practice, while in (c) and (d) coke is used as fuel. It should be remembered that coke has not been employed successfully in regular work in the Elektrometall furnaces, and this lessens the value of the estimates based on its use.

The ore used is probably magnetite, or a mixture of magnetite and hematite, such as is employed in Sweden. It must contain, judging by the amount required, about 60 per cent of iron.

The flux employed is burnt lime, although the cheaper material, raw limestone, is in regular use in the Swedish furnaces.

(2) *Output.* This important figure is not stated, but may be deduced from the figures given for the electrical consumption, as follows: for one 4,000 h.p. furnace:—

(a) White charcoal iron	29·6	tons daily.
(b) Grey „ „	27·4	„ „
(c) White coke „	28·8	„ „
(d) Grey „ „	26·1	„ „

The statement that 6 per cent of $360,000 represents 72c. per ton of iron, corresponds to an output of 27·4 tons daily per furnace.

The 4000 h.p. furnace at Domnarfvet, operating on an ore of about the same richness from July 1913 to June 1914, had an output per working day of 28·5 tons of white charcoal iron, but the average production during this time was only 26·4 tons daily. The 3000 h.p. furnace at Trollhättan produced, in 1913, from a similar ore, 22·05 tons per working day, or 20·08 tons daily over the whole time. Increasing these figures by one third (for a 4000 h.p. furnace), we have 29·4 tons and 26·8 tons of white charcoal iron daily.

In view of these figures, it appears that although a 4,000 h.p. furnace may be expected to produce 29 or 30 tons daily, while in regular operation, it will not be safe to count on more than 26 or 27 tons daily over a long period of time; that is to say, a reduction of 10 per cent on the figure stated above.

While it may be expected that with a group of three furnaces it may be possible to keep a higher load factor than with a single furnace, and although a small increase may be expected from the use of burnt lime, instead of limestone, it will probably be better in estimating for a new venture to reduce the estimate for probable outputs in each case to about 90 per cent of the above figures.

(3) *Main items of cost.* One is apt to assume that in the electric smelting of iron ores the main item of expense will be the cost of the electric energy; but, while this is undoubtedly a very important factor, it is not even the largest single item, and only amounts to about 20 per cent of the whole cost, as shown in the estimates. In each case the ore represents a

larger expense, and in making charcoal iron the fuel costs as much as the electric power.

(4) *Effect of reduced output.* If the output of the furnace is taken at 10 per cent less than Mr. Grönwall's estimate, the cost for electric power, labour and engineering, office and organization, repairs, depreciation, general expenses, and petty charges, will all be increased in the same ratio. This will amount to an increase of some 75c per ton in case (a).

(5) *Interest and Royalty.* No charge has been made for interest on capital, which might amount to about $1.00 per ton of iron, or for Royalty to be paid to the A/B. Elektrometall for the use of their type of furnace.

(6) *Cheaper ore, fuel, and flux.* On the other hand the figures set down for ore, lime, and coke (where that is used) may be considerably reduced under favourable conditions, and limestone can be substituted for lime, as in Sweden.

(7) *Value of waste gases.* The gases produced in the furnace can be used for heating an open-hearth furnace, and would have a heating power (per ton of iron) equal to that of the producer gas obtainable from about ½ ton of coal. The cost of this coal, and of gasifying it, can be written as assets in the estimate of costs, provided that the gas can be efficiently utilized.

THE RENNERFELT ELECTRIC FURNACE.

This is a new type of electric furnace for melting and refining metals. Up to the present it has found its main application in steel foundries, where it has been extremely successful in units of small and moderate size up to 2 tons capacity; and the inventor expects to extend its use to large refining steel furnaces of 50 tons or more.

Principle. The furnace is heated by means of electric arcs, as in the Héroult, or Stassano furnaces, but the principle of the arc is different. There are also essential differences in the construction of the furnace.

Electric melting furnaces heated by arcs may be divided into two main classes: (1) the "independent-arc" furnaces, such as the Moissan and Stassano furnaces, in which an arc is maintained between two or more carbon electrodes, and (2) the "direct-heating" arc furnaces, such as the Héroult and Girod furnaces, in which each arc is formed between a carbon electrode and the metal or other material to be melted. In the direct-heating arc furnaces the heat of the arc is conveyed more directly to the material to be melted than in a furnace of the Stassano type, and the efficiency will on this account tend to be higher; but the direct-heating arc is less easily operated, and causes more serious fluctuations of the power, especially when, as is usual in foundry practice, the furnace is used to melt cold steel scrap or any cold metal.

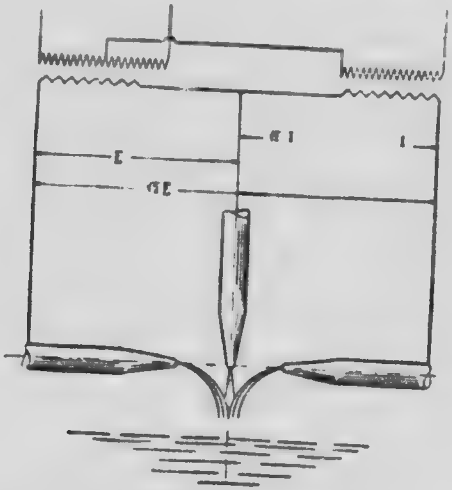


Fig. 3. Diagram of Rennerfelt furnace.

So long ago as 1892, Henri Moissan employed a magnet with his experimental furnace to force down the independent arc upon the metal to be melted. In this way, he increased the efficiency of the furnace without losing its steadiness and ease of operation. The writer was not aware of any large electric furnace in which a magnet has been used to direct the arc upon the metal to be melted;[1] but Mr. Rennerfelt has obtained the same result by a special arrangement of the electrodes without the use of an external magnet.

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[1] The Anderson furnace employs electro magnets. These are placed beneath the furnace, with the object of controlling the arc D. Carnegie, "Liquid Steel, its manufacture and cost," p. 452.

This arrangement, as shown in Fig. 3, consists of three electrodes, two of which are horizontal and the third vertical. They are supplied with two-phase current, the vertical electrode serving as the common return for the other two. The electric arc produced does not flow directly between the three electrodes, but forms a vertical flame extending downwards from the vertical electrode. In this arrangement the electric arc is deflected downwards by the magnetic force produced by the electric current flowing in the electrodes, and the larger the electric current the more strongly is the arc forced downward in the furnace.

Fig. 3 also shows the electrical connexions for obtaining low voltage two-phase current from the high voltage three-phase supply.

Construction. The furnace consists of a cylindrical steel shell mounted on trunnions, so that it can be tilted to pour out the contents. An opening at one end, furnished with a door, serves both for charging and for pouring. The shell is lined, first, with asbestos board 1¼ inch thick, to retain the heat and allow for the expansion of the bricks, then, a course of good fire bricks, and within this, a working lining of magnesite bricks, fettled, in the lower part of the furnace, with a sintering composition of dolomite or magnesite.

This mode of construction which resembles that of the Pearce and Smith basic copper converter, allows magnesite bricks to be used for the roof as well as for the hearth of the furnace, and on this account a very high temperature can be maintained without danger of melting the roof.

The arrangement of the three electrodes in the furnace is shown in Fig. 4, in which it will be seen that the furnace cavity is egg shaped, with an opening at the small end.

Graphitized electrodes are used instead of the cheaper amorphous carbon electrodes usual in electric steel-melting furnaces. On account of their greater electrical conductivity, the graphitized electrodes can be much smaller than equivalent amorphous carbon electrodes, and for this reason the difference

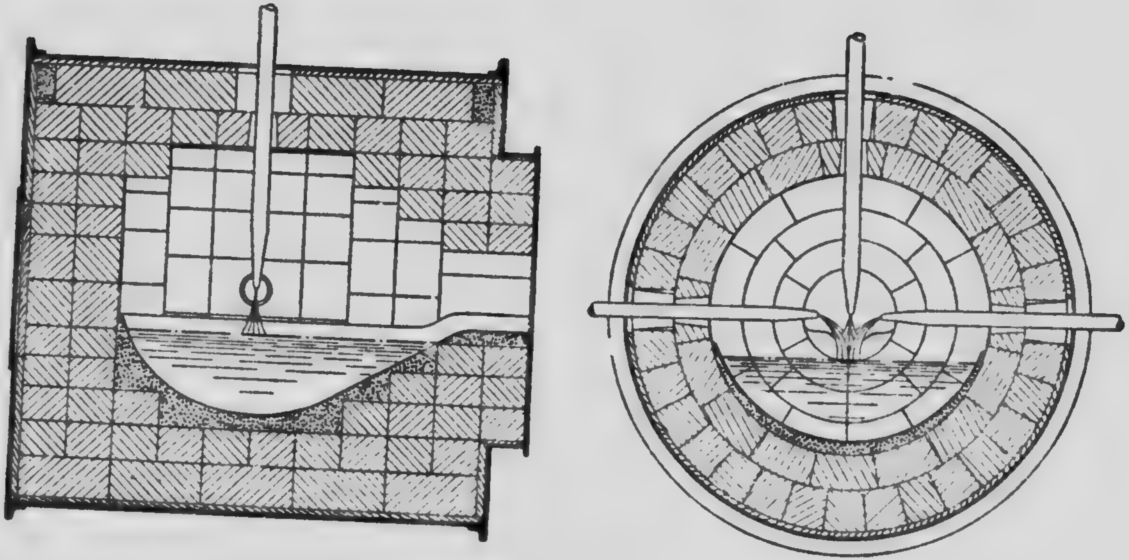


Fig. 4. Rennerfelt furnace: longitudinal and cross sections.

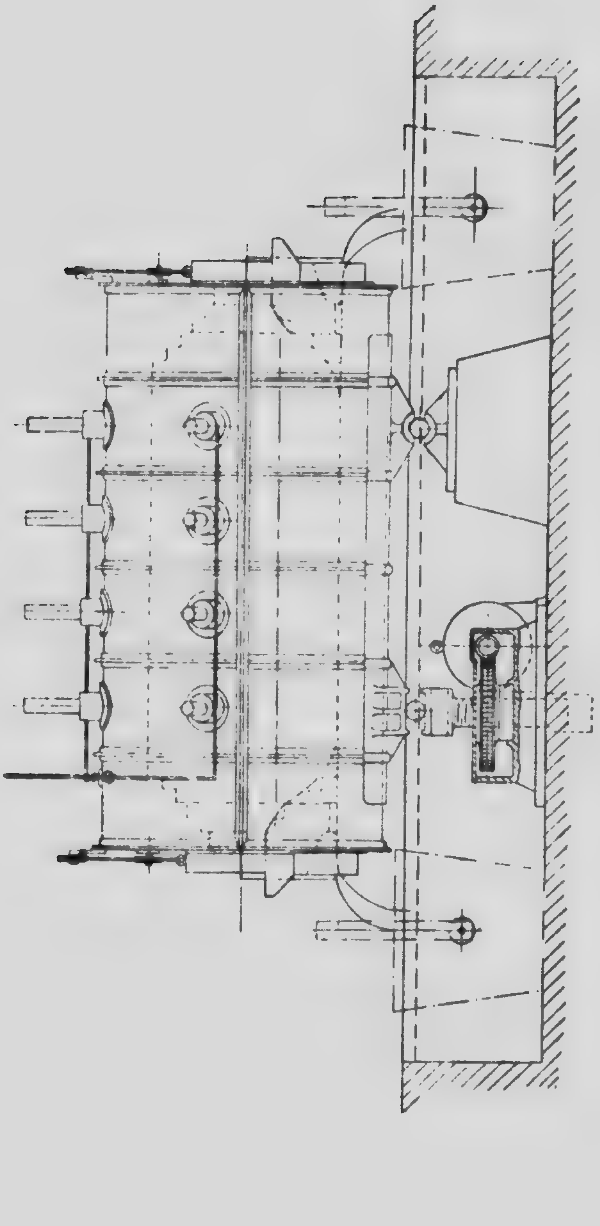


Fig. 5. Rennerfelt furnace, with multiple arcs.

in cost need not be serious. Moreover, on account of their smaller size, the furnace roof is not weakened so much by the necessary openings, even though there are three electrodes instead of two to provide for.

There has been no difficulty connected with the use of horizontal graphite electrodes up to the largest furnace so far constructed. For larger sizes (above, perhaps, 3 tons) additional sets of electrodes are provided, thus avoiding the necessity of using very large electrodes, and also spreading the heat production more evenly throughout the furnace.

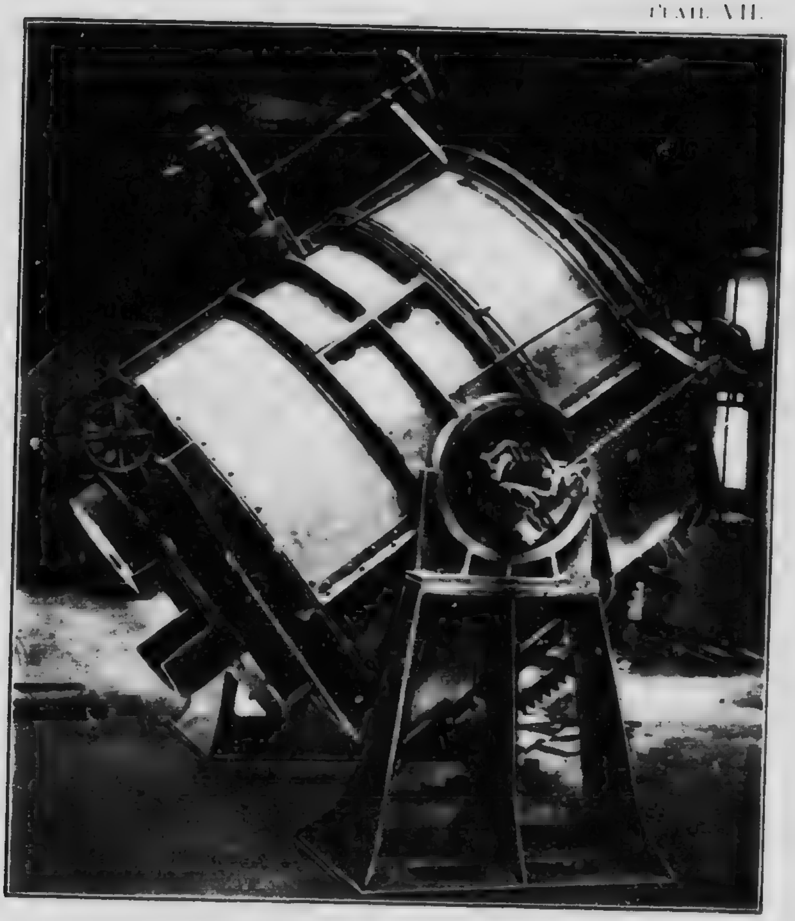
Fig. 5 shows the design of a Rennerfelt furnace having four sets of electrodes. It is cylindrical and is provided with a charging door and a tapping hole at each end. It rests on a cradle that can be tilted by a screw mechanism, instead of the trunnion support of the smaller sizes.

Plate VII is a view of a 2½ ton furnace, built in Stockolm, (where the writer saw it), and ready for shipment to Nobel's Works, St. Petersburg. The construction of the furnace, with charging door, trunnions, electrode holders, and regulators, can be clearly seen.

Results. The first furnace of this type was constructed in the year 1912, and it has been utilized very quickly by the owners of small steel foundries. The writer visited four such foundries in Sweden, and has seen three Rennerfelt furnaces varying from ½ to 1 ton capacity in regular commercial use, besides the 2½ ton furnace just referred to. The users of these furnaces were most enthusiastic in regard to them, and the furnaces appear to be very well suited for use in steel foundries, and for many purposes where small quantities of metals are to be melted.

Small furnaces of 600 Kg. capacity, will produce molten steel for castings, from a cold charge, with an expenditure of 700 or 800 K.W. hours, per ton, while in regular operation: a consumption which is quite moderate for so small a furnace. Allowing for standby losses, one may take a figure of 1000 K.W. hours per ton of steel for castings, as being a safe figure with these small furnaces. The electrode losses are given as 3 Kg. per ton of steel. In most of the foundries visited the electric power was used during the day time for running machinery

PLATE VII.



[illegible] ton, Rennerfelt furnace

and during the night for melting steel in the electric furnace. This method of utilizing power that would otherwise be wasted, is very advantageous, financially, but does not show the furnace to its best advantage in respect to kilowatt hours and electrode losses per ton of steel, which were somewhat higher than those given above. During the day time the furnace must be kept hot by means of an oil burner, or by a small amount of electrical power.

The power required for a 600 Kg. furnace, is 125 K.W., at 80 volts; and for a 1,000 Kg. furnace, 200 K.W. For larger sizes, the power needed per ton of capacity would decrease to about 120 K.W.

In addition to its normal use for melting steel for castings, the Rennerfelt furnace has been employed for melting ferromanganese for use in the Bessemer or open-hearth processes, and tests made at Hallstahammar and Ljusne with this furnace compare very favourably with similar tests using other types of furnace.[1] The melting of one ton of ferro manganese in a previously heated Rennerfelt furnace took about 450 kilowatt hours, and less than 2 lbs. of electrodes. The loss of ferro by oxidation was a little more than 1 per cent.

Up to the present, about 20 furnaces have been built for plants in Sweden, Norway, England, and Russia; the largest having a capacity of 3 tons.

Larger Sizes. Furnaces holding more than about 3 tons of steel are not heated by a single arc, as in the smaller sizes, but have two or more sets of electrodes, as shown in Fig. 5. Mr. Rennerfelt informs me that the 12-ton furnace will have three sets of electrodes and will be 16′—6″ long; it will use 1,500 kilowatts. A 40-ton furnace would have 4 sets of electrodes of 6″ and 7″ diameter, and would use 4,800 kilowatts.

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[1] A. Sahlin. The use of liquid ferro-manganese in the steel process. Journ. Iron and Steel Inst. 1914, II, p. 213.

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TABLE OF MONEY, WEIGHTS AND MEASURES.

1 Krone (Swedish) = 100 öre = 27 cents.
1 Kilogram = 2·204 lbs. avoirdupois.
1 long ton = 2,240 lbs. "
1 metric ton = 2,204 lbs. "
1 short ton = 2,000 lbs. "
1 metre = 100 centimetres = 1,000 millimetres.
1 metre = 39·37 inches.
1 centimetre = 0·39 "
1 millimetre = 0·039 "
1 litre = 1,000 cubic centimetres = 1·761 (Imperial) pints.
1 hectolitre = 100 litres = 6,103 cubic inches.
1 bushel of charcoal = 2,748 cubic inches.[1]
1 hectolitre = 2·22 bushels (of charcoal).
1 Horse power (English) = 33,000 foot pounds per minute = 746 watts.
1 Horse power (metric) = 75 kilogram metres per second = 736 watts.
1 Kilowatt-hour = 860 Kilogram calories.

Metric tons and metric horse power are in use in Sweden, and are referred to in this Report, unless otherwise specified.

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[1] This is a heaped bushel; the Imperial bushel is 8 gallons or 2,218 cubic inches. Hofman's General Metallurgy, p. 214. Journal U.S. Assoc. of Charcoal Iron Workers, 1880-81, II, pp. 128, 256.

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MICROCOPY RESOLUTION TEST CHART

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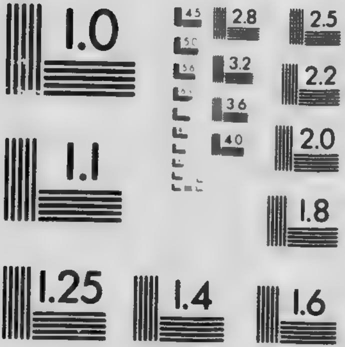

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CANADA

DEPARTMENT OF MINES

HON. LOUIS CODERRE, MINISTER; R. G. McCONNELL, DEPUTY MINISTER.

MINES BRANCH

EUGENE HAANEL, PH.D., DIRECTOR.

REPORTS AND MAPS
PUBLISHED BY THE
MINES BRANCH

REPORTS.

1. Mining conditions in the Klondike, Yukon. Report on—by Eugene Haanel, Ph.D., 1902.

†2. Great landslide at Frank, Alta. Report on—by R. G. McConnell, B.A., and R. W. Brock, M.A., 1903.

†3. Investigation of the different electro-thermic processes for the smelting of iron ores and the making of steel, in operation in Europe. Report of Special Commission—by Eugene Haanel, Ph.D., 1904.

5. On the location and examination magnetic ore deposits by magnetometric measurements—by Eugene Haanel, Ph.D., 1904.

†7. Limestones, and the lime industry of Manitoba. Preliminary report on—by J. W. Wells, M.A., 1905.

†8. Clays and shales of Manitoba: their industrial value. Preliminary report on—by J. W. Wells, M.A., 1905.

†9. Hydraulic cements (raw materials) in Manitoba; manufacture and uses of. Preliminary report on—by J. W. Wells, M.A., 1905.

†10. Mica: its occurrence, exploitation, and uses—by Fritz Cirkel, M.E., 1905. (See No. 118.)

†11. Asbestos: its occurrence, exploitation, and uses—by Fritz Cirkel, M.E., 1905. (See No. 69.)

†12. Zinc resources of British Columbia and the conditions affecting their exploitation. Report of the Commission appointed to investigate—by W. R. Ingalls, M.E., 1905.

†16. *Experiments made at Sault Ste. Marie, under Government auspices in the smelting of Canadian iron ores by the electro-thermic process. Final report on—by Eugene Haanel, Ph.D., 1907.

†17. Mines of the silver-cobalt ores of the Cobalt district: their present and prospective output. Report on—by Eugene Haanel, Ph.D., 1907.

* A few copies of the Preliminary Report, 1906, are still available.
† Publications marked thus † are out of print.

†18. Graphite: its properties, occurrences, refining, and uses—by Fritz Cirkel, M.E., 1907.

†19. Peat and lignite: their manufacture and uses in Europe—by Erik Nystrom, M.E., 1908.

†20. Iron ore deposit of Nova Scotia. Report on (Part I)—by J. E. Woodman, D.Sc.

21. Summary report of Mines Branch, 1907-8

22. Iron ore deposits of Thunder Bay and Rainy River districts. Report on—by F. Hille, M.E.

†23. Iron ore deposits along the Ottawa (Quebec side) and Gatineau rivers. Report on—by Fritz Cirkel, M.E.

24. General report on the mining and metallurgical industries of Canada, 1907-8.

25. The tungsten ores of Canada. Report on—by T. L. Walker, Ph.D. (Out of print.)

26. The mineral production of Canada, 1906. Annual report on—by John McLeish, B.A.

†27. The mineral production of Canada, 1907. Preliminary report on—by John McLeish, B.A.

†27a. The mineral production of Canada, 1908. Preliminary report on—by John McLeish, B.A.

†28. Summary report of Mines Branch, 1908.

29. Chrome iron ore deposits of the Eastern Townships. Monograph on—by Fritz Cirkel. (Supplemenatry section: Experiments with chromite at McGill University—by J. B. Porter, E.M., D.Sc.)

30. Investigation of the peat bogs and peat fuel industry of Canada, 1908. Bulletin No. 1—by Erik Nystrom, M.E., and A. Anrep, Peat Expert.

32. Investigation of electric shaft furnace, Sweden. Report on—by Eugene Haanel, Ph.D.

47. Iron ore deposits of Vancouver and Texada islands. Report on—by Einar Lindeman, M.E.

†55. The bituminous, or oil-shales of New Brunswick and Nova Scotia; also on the oil-shale industry of Scotland. Report on)—by W. R. Ells, LL.D.

58. The mineral production of Cana ., 1907 and 1908. Annual report on—by John McLeish, B.A.

† Publications marked thus † are out of print.

NOTE.—*The following parts were separately printed and issued in advance of the Annual Report for 1907-8.*

†31. Production of cement in Canada, 1908.

42. Production of iron and steel in Canada during the calendar years 1907 and 1908

43. Production of chromite in Canada during the calendar years 1907 and 1908.

44. Production of asbestos in Canada during the calendar years 1907 and 1908.

†45. Production of coal, coke, and peat in Canada during the calendar years 1907 and 1908.

46. Production of natural gas and petroleum in Canada during the calendar years 1907 and 1908.

59. Chemical analyses of special economic importance made in the laboratories at the Department of Mines, 1906-7-8. Report on—by F. G. Wait, M.A., F.C.S. (With Appendix on the commercial methods and apparatus for the analyses of oil-shales—by H. A. Leverin, Ch.E.)

Schedule of charges for chemical analyses and assays.

†62. Mineral production of Canada, 1909. Preliminary report on—by John McLeish, B.A.

63. Summary report of Mines Branch, 1909.

67. Iron deposits of the Bristol mine, Pontiac county, Quebec. Bulletin No. 2—by Einar Lindeman, M.E., and Geo. C. Mackenzie, B.Sc.

†68. Recent advances in the construction of electric furnaces for the production of pig iron, steel, and zinc. Bulletin No. 3—by Eugene Haanel, Ph.D.

69. Chrysotile-asbestos: its occurrence, exploitation, milling, and uses. Report on—by Fritz Cirkel, M.E. (Second edition, enlarged.)

†71. Investigation of the peat bogs and peat industry of Canada, 1909-10, to which is appended Mr. Alf. Larson's paper on Dr. M. Ekenberg's wet-carbonizing process: from Teknisk Tidskrift, No. 12, December 26, 1908—translation by Mr. A. v. Anrep, Jr.; also a translation of Lieut. Ekelund's pamphlet entitled 'A solution of the peat problem,' 1909, describing the Ekelund process for the manufacture of peat powder, by Harold A. Leverin, Ch.E. Bulletin No. 4—by A. v. Anrep. (Second edition, enlarged.)

82. Magnetic concentration experiments. Bulletin No. 5—by Geo. C. Mackenzie, B.Sc.

† Publications marked thus † are out of print.

83. An investigation of the coals of Canada with reference to their economic qualities: as conducted at McGill University under the authority of the Dominion Government. Report on—by J. B. Porter, E.M., D.Sc., R. J. Durley, Ma.E., and others.
    - Vol. I—Coal washing and cooking tests.
    - Vol. II—Boiler and gas producer tests.
    - Vol. III—(Out of print.)
        - Appendix I
            - Coal washing tests and diagrams.
    - Vol. IV
        - Appendix II
            - Boiler tests and diagrams.
    - Vol. V—(Out of print.)
        - Appendix III
            - Producer tests and diagrams.
    - Vol. VI
        - Appendix IV
            - Coking tests.
        - Appendix V
            - Chemical tests

†84. Gypsum deposits of the Maritime provinces of Canada—including the Magdalen islands. Report on—by W. F. Jennison, M.E. (See No. 245.)

88 The mineral production of Canada, 1909. Annual report on—by John McLeish, B.A.

Note.—*The following parts were separately printed and issued in advance of the Annual Report for 1909.*

†79. Production of iron and steel in Canada during the calendar year 1909.
†80. Production of coal and coke in Canada during the calendar year 1909.
85. Production of cement, lime, clay products, stone, and other structural materials during the calendar year 1909.

89. Reprint of presidential address delivered before the American Peat Society at Ottawa [illegible] 1910. By Eugene Haanel, Ph.D.

90. Proceedings of confer [illegible] osives.

92. Investigation of the [illegible] dustry in the Dominion of Canada, 1901. Report o [illegible] apt. Arthur Desborough. (Second edition.)

93. Molybdenum ores of Canada. Report on—by Professor T. L. Walker, Ph.D.

100. The building and ornamental stones of Canada: Building and ornamental stones of Ontario. Report on—by Professor W. A. Parks, Ph.D.

102. Mineral production of Canada, 1910. Preliminary report on—by John McLeish, B.A.

† Publications marked thus † are out of print.

†103. Summary report of Mines Branch, 1910

104. Catalogue of publications of Mines Branch, from 1902 to 1911, containing tables of contents and lists of maps, etc

105. Austin Brook iron-bearing district. Report on—by E. Lindeman, M.E.

110. Western portion of Torbrook iron ore deposits, Annapolis county, N.S. Bulletin No. 7—by Howells Frechette, M.Sc.

111. Diamond drilling at Point Mamainse, Ont. Bulletin No. 6—by A. C. Lane, Ph.D., with introductory by A. W. G. Wilson, Ph.D.

118. Mica: its occurrence, exploitation, and uses. Report on—by Hugh S. de Schmid, M.E.

142. Summary report of Mines Branch, 1911.

143. The mineral production of Canada, 1910. Annual report on—by John McLeish, B.A.

Note.—*The following parts were separately printed and issued in advance of the Annual Report for 1910.*

- †114. Production of cement, lime, clay products, stone, and other materials in Canada, 1910
- †115. Production of iron and steel in Canada during the calendar year 1910.
- †116. Production of coal and coke in Canada during the calendar year 1910
- †117. General summary of the mineral production of Canada during the calendar year 1910.

145. Magnetic iron sands of Natashkwan, Saguenay county, Que. Report on—by Geo. C. Mackenzie, B.Sc.

†150. The mineral production of Canada, 1911. Preliminary report on—by John McLeish, B.A.

151. Investigation of the peat bogs and peat industry of Canada, 1910-11. Bulletin No. 8—by A. v. Anrep.

154. The utilization of peat for fuel for the production of power, being a record of experiments conducted at the Fuel Testing Station, Ottawa, 1910-11. Report on—by B. F. Haanel, B.Sc.

167. Pyrites in Canada: its occurrence, exploitation, dressing and uses. Report on—by A. W. G. Wilson, Ph.D.

170. The nickel industry: with special reference to the Sudbury region, Ont. Report on—by Professor A. P. Coleman, Ph.D.

184. Magnetite occurrences along the Central Ontario railway. Report on—by E. Lindeman, M.E.

201. The mineral production of Canada during the calendar year 1911. —Annual report on—by John McLeish, B.A.

† Publications marked thus † are out of print.

NOTE.—*The following parts were separately printed and issued in advance of the Annual Report for 1911.*

181. Production of cement, lime, clay products, stone, and other structural materials in Canada during the calendar year 1911. Bulletin on—by John McLeish, B.A.

†182. Production of iron and steel in Canada during the calendar year 1911. Bulletin on—by John McLeish, B.A.

183. General summary of the mineral production in Canada during the calendar year 1911. Bulletin on—by John McLeish, B.A.

†199. Production of copper, gold, lead, nickel, silver, zinc, and other metals of Canada, during the calendar year 1911. Bulletin on—by C. T. Cartwright, B.Sc.

†200. The production of coal and coke in Canada during the calendar year 1911. Bulletin on—by John McLeish, B.A.

203. Building stones of Canada—Vol. II: Building and ornamental stones of the Maritime Provinces. Report on—by W. A. Parks, Ph.D.

209. The copper smelting industry of Canada. Report on—by A. W. G. Wilson, Ph.D.

216. Mineral production of Canada, 1912. Preliminary report on—by John McLeish, B.A.

222. Lode mining in Yukon: an investigation of the quartz deposits of the Klondike division. Report on—by T. A. MacLean, B.Sc.

224. Summary report of the Mines Branch, 1912.

227. Sections of the Sydney coal fields—by J. G. S. Hudson, M.E.

†229. Summary report of the petroleum and natural gas resources of Canada, 1912—by F. G. Clapp, A.M. (See No. 224.)

230. Economic minerals and mining industries of Canada.

245. Gypsum in Canada: its occurrence, exploitation, and technology. Report on—by L. H. Cole, B.Sc.

254. Calabogie iron-bearing district. Report on—by E. Lindeman, M.E.

259. Preparation of metallic cobalt by reduction of the oxide. Report on—by H. T. Kalmus, B.Sc., Ph.D.

262. The mineral production of Canada during the calendar year 1912. Annual report on—by John McLeish, B.A.

NOTE.—*The following parts were separately printed and issued in advance of the Annual Report for 1912.*

238. General summary of the mineral production of Canada, during the calendar year 1912. Bulletin on—by John McLeish, B.A.

† Publications marked thus † are out of print.

- †247. Production of iron and steel in Canada during the calendar year 1912. Bulletin on—by John McLeish, B.A.
- †256. Production of copper, gold, lead, nickel, silver, zinc, and other metals of Canada, during the calendar year 1912—by C. T. Cartwright, B.Sc.
- †257. Production of cement, lime, clay products, stone, and other structural materials during the calendar year 1912. Report on—by John McLeish, B.A.
- †258. Production of coal and coke in Canada, during the calendar year 1912. Bulletin on—by John McLeish, B.A.

266. Investigation of the peat bogs and peat industry of Canada, 1911 and 1912. Bulletin No. 9—by A. v. Anrep.

279. Building and ornamental stones of Canada. Vol. III: Building and ornamental stones of Quebec. Report on—by W. A. Parks, Ph.D.

281. The bituminous sands of Northern Alberta. Report on—by S. C. Ells, M.E.

283. Mineral production of Canada, 1913. Preliminary report on—by John McLeish, B.A.

285. Summary report of the Mines Branch, 1913.

291. The petroleum and natural gas resources of Canada. Report on—by F. G. Clapp, A.M., and others:
    Vol. I—Technology and Exploitation.
    Vol. II—Occurrence of petroleum and natural gas in Canada.
        Also separates of Vol. II, as follows:—
            Part 1, Eastern Canada.
            Part 2, Western Canada.

299. Peat, lignite, and coal: their value as fuels for the production of gas and power in the by-product recovery producer. Report on—by B. F. Haanel, B.Sc.

303. Moose Mountain iron-bearing district. Report on—by E. Lindeman, M.E.

305. The non-metallic minerals used in the Canadian manufacturing industries. Report on—by Howells Fréchette, M.Sc.

309. The physical properties of cobalt, Part [illegible] Report on—by H. T. Kalmus, B.Sc., Ph.D.

320. The mineral production of Canada during the calendar year 1913. Annual report on—by John Mc[illegible]

    Note.—*The following parts were se[illegible] and issued in advance of the Annual Report for* [illegible]

    315. The production of iron and [illegible] the calendar year 1913. Bulletin on—by John [illegible], B.A.

† Publications marked thus † are out of print

316. The production of coal and coke during the calendar year 1913. Bulletin on—by John McLeish, B.A.

317. The production of copper, gold, lead, nickel, silver, zinc, and other metals, during the calendar year 1913. Bulletin on—by C. T. Cartwright, B.Sc.

318. The production of cement, lime, clay products, and other structural materials, during the calendar year 1913. Bulletin on—by John McLeish, B.A.

319. General summary of the mineral production of Canada during the calendar year 1913. Bulletin on—by John McLeish, B.A.

322. Economic minerals and mining industries of Canada. (Revised Edition).

323. The Products and by-products of coal. Report on—by Edgar Stansfield, M.Sc., and F. E. Carter, B.Sc., Dr. Ing.

325. The salt industry of Canada. Report on—by L. H. Cole, B.Sc.

331. The investigation of six samples of Alberta lignites. Report on—by B. F. Haanel, B.Sc., and John Blizard, B.Sc.

334. Electro-plating with cobalt and its alloys. Report on—by H. T. Kalmus, B.Sc., Ph.D.

336. Notes on clay deposits near McMurray, Alberta. Bulletin No. 10—by S. C. Ells, B.A., B.Sc.

344. Electrothermic smelting of iron ores in Sweden. Report on—by Alfred Stansfield, D.Sc., A.R.S.M., F.R.S.C.

The Division of Mineral Resources and Statistics has prepared the following lists of mine, smelter, and quarry operators. Metal mines and smelters, Coal mines, Stone quarry operators, Manufacturers of clay products, and Manufacturers of lime; copies of the lists may be obtained on application.

IN THE PRESS.

338. Coals of Canada: Vol. VII. Weathering of coal. Report on—by J. B. Porter, E.M., D.Sc., Ph.D.

346. Summary report of the Mines Branch for 1914.

348. Production of coal and coke in Canada during the calendar year, 1914. Bulletin on—by J. McLeish, B.A.

349. Production of iron and steel in Canada during the calendar year, 1914. Bulletin on—by J. McLeish, B.A.

350. Production of copper, gold, lead, nickel, silver, zinc, and other metals, during the calendar year, 1914. Bulletin on—by J. McLeish, B.A.

FRENCH TRANSLATIONS.

†4. Rapport de la Commission nommée pour étudier les divers procédés électro-thermiques po[illegible] la réduction des minerais de fer et la fabrication de l'acie[illegible] [illegible]ployés [illegible] Europe—by Eugene Haanel, Ph.D. (French Edition), 19[illegible]

26a. The mineral production of Canada, 1906. Annual report on—by John McLeish, B.A.

†28a. Summary report of Mines Branch, 1908.

[illegible] Bituminous or oil-shales of New Brunswick and Nova Scotia; also on the oil-shale industry of Scotland. Report on—by R. W. Ells, [illegible]

81. [illegible]le-asbestos, its occurrence, exploitation, milling, and uses. [illegible]ort on—by Fritz Cirkel, M.E.

100a. The building and ornamental stones of Canada: Building and ornamental stones of Ontario. Report on—by W. A. Parks, Ph.D.

149. Magnetic iron sands of Natashkwan, Saguenay county, Que. Report on—by Geo. C. Mackenzie, B.Sc.

155. The utilization of peat fuel for the production of power, being a record of experiments conducted at the Fuel Testing Station, Ottawa, 1910-11. Report on—by B. F. Haanel, B.Sc.

156. The tungsten ores of Canada. Report on—by T. L. Walker, Ph.D.

169. Pyrites in Canada: its occurrences, exploitation, dressing, and uses. Report on—by A. W. G. Wilson, Ph.D.

180. Investigation of the peat bogs, and peat industry of Canada, 1910-11. Bulletin No. 8—by A. v. Anrep.

195. Magnetite occurrences along the Central Ontario railway. Report on—by E. Lindeman, M.E.

196. Investigation of the peat bogs and peat industry of Canada, 1909-10; to which is appended Mr. Alf. Larson's paper on Dr. M. Ekenburg's wet-carbonizing process: from Teknisk Tidskrift, No. 12, December 26, 1908—translation by Mr. A. v. Anrep; also a translation of Lieut. Ekelund's pamphlet entitled "A solution of the peat problem," 1909, describing the Ekelund process for the manufacture of peat powder, by Harold A. Leverin, Ch.E. Bulletin No. 4—by A. v. Anrep. (Second Edition, enlarged.)

197. Molybdenum ores of Canada. Report on—by T. L. Walker, Ph.D.

198. Peat and lignite: their manufacture and uses in Europe. Report on—by Erik Nystrom, M.E., 1908.

202. Graphite: its properties, occurrences, refining, and uses. Report on—by Fritz Cirkel, M.E., 1907.

† Publications marked thus † are out of print.

219. Austin Brook iron-bearing district. Report on—by E. Lindeman, M.E.

224a. Mines Branch Summary report for 1912.

226. Chrome iron ore deposits of the Eastern Townships. Monograph on—by Fritz Cirkel, M.E. (Supplementary section: Experiments with chromite at McGill University—by J. B. Porter, E.M., D.Sc.)

321. Economic minerals and mining industries of Canada.

233. Gypsum deposits of the Maritime Provinces of Canada—including the Magdalen islands. Report on—by W. F. Jennison, M.E.

263. Recent advances in the construction of electric furnaces for the production of pig iron, steel, and zinc. Bulletin No. 3—by Eugene Haanel, Ph.D.

264. Mica: its occurrence, exploitation, and uses. Report on—by Hugh S. de Schmid, M.E.

265. Annual mineral production of Canada, 1911. Report on—by John McLeish, B.A.

287. Production of iron and steel in Canada during the calendar year 1912. Bulletin on—by John McLeish, B.A.

288. Production of coal and coke in Canada, during the calendar year 1912. Bulletin on—by John McLeish, B.A.

289. Production of cement, lime, clay products, stone, and other structural materials during the calendar year 1912. Bulletin on—by John McLeish, B.A.

290. Production of copper, gold, lead, nickel, silver, zinc, and other metals of Canada during the calendar year 1912. Bulletin on—by C. T. Cartwright, B.Sc.

307. Catalogue of French publications of the Mines Branch and of the Geological Survey, up to July, 1914.

308. An investigation of the coals of Canada with reference to their economic qualities: as conducted at McGill University under the authority of the Dominion Government. Report on—by J. B. Porter, E.M., D.Sc., R. J. Durley, Ma.E., and others—
   Vol. I—Coal washing and coking tests.
   Vol. II—Boiler and gas producer tests.

314. Iron ore deposits, Bristol mine, Pontiac county, Quebec, Report on—by E. Lindeman, M.E.

IN THE PRESS.

179. The nickel industry: with special reference to the Sudbury region, Ont. Report on—by Professor A. P. Coleman, Ph.D.

204. Building stones of Canada—Vol. II: Building and ornamental stones of the Maritime Provinces. Report on—by W. A. Parks, Ph.D.

223. Lode Mining in the Yukon: an investigation of quartz deposits in the Klondike division. Report on—by T. A. MacLean, B.Sc.

246. Gypsum in Canada: its occurrence, exploitation, and technology. Report on—by L. H. Cole, B.Sc.

308. An investigation of the coals of Canada with reference to their economic qualities: as conducted at McGill University under the authority of the Dominion Government. Report on—by J. B. Porter, E.M., D.Sc., R. J. Durley, Ma.E., and others—
    Vol. III—
        Appendix I
            Coal washing tests and diagrams.
    Vol. IV—
        Appendix II
            Boiler tests and diagrams.

286. Summary report of Mines Branch, 1913.

321. Annual mineral production of Canada, during the calendar year 1913. Report on—by J. McLeish, B.A.

MAPS.

†6. Magnetometric survey, vertical intensity: Calabogie mine, Bagot township, Renfrew county, Ontario—by E. Nystrom, 1904. Scale 60 feet to 1 inch. Summary report 1905. (See Map No, 249.)

†13. Magnetometric survey of the Belmont iron mines, Belmont township, Peterborough county, Ontario—by B. F. Haanel, 1905. Scale 60 feet to 1 inch. Summary report, 1906. (See Map No. 186.)

†14. Magnetometric survey of the Wilbur mine, Lavant township, Lanark county, Ontario—by B. F. Haanel, 1905. Scale 60 feet to 1 inch. Summary report, 1906.

†33. Magnetometric survey, vertical intensity: lot 1, concession VI, Mayo township, Hastings county, Ontario—by Howells Fréchette, 1909. Scale 60 feet to 1 inch. (See Maps Nos. 191 and 191A.)

†34. Magnetometric survey, vertical intensity: lots 2 and 3, concession VI, Mayo township, Hastings county, Ontario—by Howells Fréchette, 1909. Scale 60 feet to 1 inch. (See Maps Nos. 191 and 191A.)

†35. Magnetometric survey, vertical intensity: lots 10, 11, and 12 concession IX, and lots 11 and 12, concession VIII, Mayo township, Hastings county. Ontario—by Howells Fréchette, 1909. Scale 60 feet to 1 inch. (See Maps Nos. 191 and 191A).

*36. Survey of Mer Bleue peat bog, Gloucester township, Carleton county, and Cumberland township, Russell county, Ontario—by Erik Nystrom, and A. v. Anrep. (Accompanying report No. 30.)

*37. Survey of Alfred peat bog, Alfred and Caledonia townships, Prescott county, Ontario—by Erik Nystrom and A. v. Anrep. (Accompanying report No. 30.)

*38. Survey of Welland peat bog, Wainfleet and Humberstone townships, Welland county, Ontario—by Erik Nystrom and A. v. Anrep. (Accompanying report No. 30.)

*39. Survey of Newington peat bog, Osnabruck, Roxborough, and Cornwall townships, Stormont county, Ontario—by Erik Nystrom and A. v. Anrep. (Accompanying report No. 30.)

*40. Survey of Perth peat bog, Drummond township, Lanark county, Ontario—by Erik Nystrom and A. v. Anrep. (Accompanying report No. 30.)

†41. Survey of Victoria Road peat bog, Bexley and Carden townships, Victoria county, Ontario—Erik Nystrom and A. v. Anrep. (Accompanying report No. 30.)

*48. Magnetometric survey of Iron Crown claim at Nimpkish (Klaanch) river, Vancouver island, B.C.—by E. Lindeman. Scale 60 feet to 1 inch. (Accompanying report No. 47.)

Note.—1. Maps marked thus * are to be found only in reports.
2. Maps marked thus † have been printed independently of reports, hence can be procured separately by applicants.

*49. Magnetometric survey of Western Steel Iron claim, at Sechart, Vancouver island, B.C.—By E. Lindeman. Scale 60 feet to 1 inch. (Accompanying report No. 47.)

*53. Iron ore occurrences, Ottawa and Pontiac counties, Quebec, 1908—by J. White and Fritz Cirkel. (Accompanying report No. 23.)

*54. Iron ore occurrences, Argenteuil county, Quebec, 1908—by Fritz Cirkel. (Accompanying report No. 23.) (Out of print.)

*57. The productive chrome iron ore district of Quebec—by Fritz Cirkel. (Accompanying report No. 29.)

†60. Magnetometric survey of the Bristol mine, Pontiac county, Quebec—by E. Lindeman. Scale 200 feet to 1 inch. (Accompanying report No. 67.)

†61. Topographical map of Bristol mine, Pontiac county, Quebec—by E. Lindeman. Scale 200 feet to 1 inch. (Accompanying report No. 67.)

†64. Index map of Nova Scotia: Gypsum—by W. F. Jennison.

†65. Index map of New Brunswick: Gypsum—by W. F. Jennison.

†66. Map of Magdalen islands: Gypsum—by W. F. Jennison.

(Accompanying report No. 84.)

†70. Magnetometric survey of Northeast Arm iron range, Lake Timagami, Nipissing district, Ontario—by E. Lindeman. Scale 200 feet to 1 inch. (Accompanying report No. 63.)

†72. Brunner peat bog, Ontario—by A. v. Anrep.

†73. Komako peat bog, Ontario—by A. v. Anrep.

†74. Brockville peat bog, Ontario—by A. v. Anrep.

†75. Rondeau peat bog, Ontario—by A. v. Anrep.

†76. Alfred peat bog, Ontario—by A. v. Anrep.

†77. Alfred peat bog, Ontario main ditch profile—by A. v. Anrep.

(Accompanying report No. 71.) (Out of print.)

†78. Map of asbestos region, Province of Quebec, 1910—by Fritz Cirkel Scale 1 mile to 1 inch. (Accompanying report No. 69.)

†94. Map showing Cobalt, Gowganda, Shiningtree, and Porcupine districts—by L. H. Cole. (Accompanying Summary report, 1910.)

†95. General map of Canada, showing coal fields. (Accompanying report No. 83—by Dr. J. B. Porter.)

†96. General map of coal fields of Nova Scotia and New Brunswick. (Accompanying report No. 83—by Dr. J. B. Porter.)

†97. General map showing coal fields in Alberta, Saskatchewan, and Manitoba. (Accompanying report No. 83—by Dr. J. B. Porter).

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†98. General map of coal fields in British Columbia. (Accompanying report No. 83—by Dr. J. B. Porter.)

†99. General map of coal field in Yukon Territory. (Accompanying report No. 83—by Dr. J. B. Porter.)

†106 Geological map of Austin Book iron-bearing district, Bathurst township, Gloucester county, N.B.—by E. Lindeman. Scale 400 feet to 1 inch. (Accompanying report No. 105.)

†107 Magnetometric survey, vertical intensity: Austin Book iron-bearing district—by E. Lindeman. Scale 400 feet to 1 inch. (Accompanying report No. 105.)

†108. Index map showing iron-bearing area at Austin Brook—by E. Lindeman. (Accompanying report No. 105.)

*112. Sketch plan showing geology of Point Mamainse, Ont.—by Professor A. C. Lane. Scale 4,000 feet to 1 inch. (Accompanying report No. 111.)

†113. Holland peat bog Ontario—by A. v. Anrep. (Accompanying report No. 151.)

*119–137. Mica: township maps, Ontario and Quebec—by Hugh S. de Schmid. (Accompanying report No. 118.)

†138. Mica: showing location of principal mines and occurrences in the Quebec mica area—by Hugh S. de Schmid. Scale 3·95 miles to 1 inch. (Accompanying report No. 118.)

†139. Mica: showing location of principal mines and occurrences in the Ontario mica area—by Hugh S. de Schmid. Scale 3·95 miles to 1 inch. (Accompanying report No. 118.)

†140. Mica: showing distribution of the principal mica occurrences in the Dominion of Canada—by Hugh S. de Schmid. Scale 3·95 miles to 1 inch. (Accompanying report No. 118.)

†141. Torbrook iron-bearing district Annapolis county, N.S.—by Howells Fréchette. Scale 400 feet to 1 inch. (Accompanying report No. 110.)

†146. Distribution of iron ore sands of the iron ore deposits on the north shore of the River and Gulf of St. Lawrence, Canada—by Geo. C. Mackenzie. Scale 100 miles to 1 inch. (Accompanying report No. 145.)

†147. Magnetic iron sand deposits in relation to Natashkwan harbour and Great Nataskwan river, Que. (Index Map)—by Geo. C. Mackenzie. Scale 40 chains to 1 inch. (Accompanying report No. 145.)

†148. Natashkwan magnetic iron sand deposits, Saguenay county, Que.—by Geo. C. Mackenzie. Scale 1,000 feet to 1 inch. (Accompanying report No. 145.)

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†152. Map showing the location of peat bogs investigated in Ontario—by A. v. Anrep.

†153. Map showing the location of peat bog as investigated in Manitoba—by A. v. Anrep.

†157. Lac du Bonnet peat bog, Manitoba—by A. v. Anrep.

†158. Transmission peat bog, Manitoba—by A. v. Anrep.

†159. Corduroy peat bog, Manitoba—by A. v. Anrep.

†160. Boggy Creek peat bog, Manitoba—by A. v. Anrep.

†161. Rice Lake peat bog, Manitoba—by A. v. Anrep.

†162. Mud Lake peat bog, Manitoba—by A. v. Anrep.

†163. Litter peat bog, Manitoba—by A. v. Anrep.

†164. Julius peat litter bog, Manitoba—by A. v. Anrep.

†165. Fort Frances peat bog, Ontario—by A. v. Anrep.

(Accompanying report No. 151.)

†166. Magnetometric map of No. 3 mine, lot 7, concessions V. and VI, McKim township, Sudbury district, Ont.—by E. Lindeman. (Accompanying Summary report, 1911.)

†168. Map showing pyrites mines aad prospects in Eastern Canada, and their relation to the United States market—by A. W. G. Wilson. Scale 125 miles to 1 inch. (Accompanying report No. 167.)

†171. Geological map of Sudbury nickel region, Ont. by Prof. A. P. Coleman. Scale 1 mine to 1 inch. (Accompanying report No. 170.)

†172. Geological map of Victoria mine—by Prof. A. P. Coleman.

†173. „ Crean Hill mine—by Prof. A. P. Coleman.

†174. „ Creighton mine—by Prof. A. P. Coleman.

(Accompanying report No. 170.)

†175. „ showing contact of norite and Laurentian in vicinity of Creighton mine—by Prof. A. P. Coleman. (Accompanying report No. 170.)

†176. „ Copper Cliff offset—by Prof. A. P. Coleman. (Accompanying report No. 170.)

†177. „ No. 3 mine—by Prof. A. P. Coleman. (Accompanying report No. 170.)

†178. „ showing vicinity of Stobie and No. 3 mines—by Prof. A. P. Coleman. (Accompanying report No. 170.)

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†185. Magnetometric survey, vertical intensity: Blairton iron mine, Belmont township, Peterborough county, Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch. (Accompanying report No. 184.)

†185a. Geological map, Blairton iron mine, Belmont township, Peterborough county, Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch. (Accompanying report No. 184.)

†186. Magnetometric survey, Belmont iron mine, Belmont township, Peterborough county, Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch. (Accompanying report No. 184.)

†186a. Geological map, Belmont iron mine, Belmont township, Peterborough county, Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch. (Accompanying report No. 184.)

†187. Magnetometric survey, vertical intensity: St. Charles mine, Tudor township, Hastings county, Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch. (Accompanying report No. 184.)

†187a. Geological map, St. Charles mine, Tudor township, Hastings county, Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch. (Accompanying report No. 184.)

†188. Magnetometric survey, vertical intensity: Baker mine, Tudor township, Hastings county, Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch. (Accompanying report No. 184.)

†188a. Geological map, Baker mine, Tudor township, Hastings county Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch. (Accompanying report No. 184.)

†189. Magnetometric survey, vertical intensity: Ridge iron ore deposits, Wollaston township, Hastings county Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch. (Accompanying report No. 184.)

†190. Magnetometric survey, vertical intensity: Coehill and Jenkins mines, Wollaston township, Hastings county, Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch. (Accompanying report No. 184.)

†190a. Geological map, Coehill and Jenkins mines, Wollaston township, Hastings county, Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch. (Accompanying report No. 184.)

†191. Magnetometric survey, vertical intensity: Bessemer iron ore deposits, Mayo township, Hastings county, Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch. (Accompanying report No. 184.)

†191a. Geological map, Bessemer iron ore deposits, Mayo township, Hastings county, Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch. (Accompanying report No. 184.)

†192. Magnetometric survey, vertical intensity: Rankin, Childs, and Stevens mines, Mayo township, Hastings county, Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch. (Accompanying report No. 184.)

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†192a. Geological map, Rankin, Childs, and Stevens mines, Mayo township, Hastings county, Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch. (Accompanying report No. 184.)

†193. Magnetometric survey, vertical intensity: Kennedy property, Carlow township, Hastings county, Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch. (Accompanying report No. 184.)

†193a. Geological map, Kennedy property, Carlow township, Hastings county, Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch. (Accompanying report No. 184.)

†194. Magnetometric survey, vertical intensity: Bow Lake iron ore occurrences, Faraday township, Hastings county, Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch. (Accompanying report No. 184.)

†204. Index map, magnetite occurrences along the Central Ontario railway—by E. Lindeman, 1911. (Accompanying report No. 184.)

†205. Magnetometric map, Moose Mountain iron-bearing district, Sudbury district, Ontario: Deposits Nos. 1, 2, 3, 4, 5, 6, and 7—by E. Lindeman, 1911. (Accompanying report No 303.)

†205a. Geological map, Moose Mountain iron-bearing district, Sudbury district, Ontario, Deposits Nos. 1, 2, 3, 4, 5, 6, and 7—by E. Lindeman. (Accompanying report No. 303.)

†206. Magnetometric survey of Moose Mountain iron-bearing district, Sudbury district, Ontario: northern part of deposit No. 2—by E. Lindeman, 1912. Scale 200 feet to 1 inch. (Accompanying report No. 303.)

†207. Magnetometric survey of Moose Mountain iron-bearing district, Sudbury district, Ontario: Deposits Nos. 8, 9, and 9A—by E. Lindeman, 1912. Scale 200 feet to 1 inch. (Accompanying report No. 303.)

†208. Magnetometric survey of Moose Mountain iron-bearing district, Sudbury district, Ontario: Deposit No. 10—by E. Lindeman, 1912. Scale 200 feet to 1 inch. (Accompanying report No. 303.)

†208a. Magnetometric survey, Moose Mountain iron-bearing district, Sudbury district, Ontario: eastern portion of Deposit No. 11—by E Lindeman, 1912. Scale 200 feet to 1 inch. (Accompanying report No. 303.)

08b. Magnetometric survey, Moose Mountain iron-bearing district, Sudbury district, Ontario: western portion of deposit No. 11—by E. Lindeman, 1912. Scale 200 feet to 1 inch. (Accompanying report No. 303.)

†208c. General geological map, Moose Mountain iron-bearing district, Sudbury district, Ontario—by E. Lindeman, 1912. Scale 800 feet to 1 inch. (Accompanying report No. 303.)

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†210. Location of copper smelters in Canada—by A. W. G. Wilson. Scale 197·3 miles to 1 inch. (Accompanying report No. 209.)

†215. Province of Alberta: showing properties from which samples of coal were taken for gas producer tests, Fuel Testing Division, Ottawa. (Accompanying Summary report, 1912.)

†220. Mining districts, Yukon. Scale 35 miles to 1 inch—by T. A. MacLean (Accompanying report No. 222.)

†221. Dawson mining district, Yukon. Scale 2 miles to 1 inch—by T. A. MacLean. (Accompanying report No. 222.)

*228. Index map of the Sydney coal fields, Cape Breton, N.S. (Accompanying report No. 227.)

†232. Mineral map of Canada. Scale 100 miles to 1 inch. (Accompanying report No. 230.)

†239. Index map of Canada showing gypsum occurrences. (Accompanying report No. 245.)

†240. Map showing Lower Carboniferous formation in which gypsum occurs in the Maritime provinces. Scale 100 miles to 1 inch. (Accompanying report No. 345.)

†241. Map showing relation of gypsum deposits in Northern Ontario to railway lines. Scale 100 miles to 1 inch. (Accompanying report No. 245.)

†242. Map, Grand River gypsum deposits, Ontario. Scale 4 miles to 1 inch. (Accompanying report No. 245.)

†243. Plan of Manitoba Gypsum Co's properties. (Accompanying report No. 245.)

†244. Map showing relation of gypsum deposits in British Columbia to railway lines and market. Scale 35 miles to 1 inch. (Accompanying report No. 245.)

†249. Magnetometric survey, Caldwell and Campbell mines, Calabogie district, Renfrew county, Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch.

†250. Magnetometric survey, Black Bay or Williams mine, Calabogie district, Renfrew county, Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch. (Accompanying report No. 254.)

†251. Magnetometric survey, Bluff Point iron mine, Calabogie district, Renfrew county, Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch. (Accompanying report No. 254.)

†252. Magnetometric survey, Culhane mine, Calabogie district, Renfrew county, Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch (Accompanying report No. 254.)

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†253. Magnetometric survey, Martel or Wilson iron mine, Calabogie district, Renfrew county, Ontario—by E. Lindeman, 1911. Scale 200 feet to 1 inch. (Accompanying report No. 254.)

†261. Magnetometric survey, Northeast Arm iron range, lot 339 E.T.W. Lake Timagami, Nipissing district, Ontario—by E. Nystrom, 1903. Scale 200 feet to 1 inch.

†268. Map of peat bogs investigated in Quebec—by A. v. Anrep, 1912.

†269. Large Tea Field peat bog, Quebec " "

†270. Small Tea Field peat bog, Quebec " "

†271. Lanoraie peat bog, Quebec " "

†272. St. Hyacinthe peat bog, Quebec " "

†273. Rivière du Loup peat bog " "

†274. Cacouna peat bog " "

†275. Le Parc peat bog, Quebec " "

†276. St. Denis peat bog, Quebec " "

†277. Rivière Ouelle peat bog, Quebec " "

†278. Moose Mountain peat bog, Quebec " "

†284. Map of northern portion of Alberta, showing position of outcrops of bituminous sand. Scale 12½ miles to 1 inch. (Accompanying report No. 281.)

†293. Map of Dominion of Canada, showing the occurrences of oil, gas, and tar sands. Scale 197 miles to 1 inch. (Accompanying report No. 291.)

†294. Reconnaissance map of part of Albert and Westmorland counties New Brunswick. Scale 1 mile to 1 inch. (Accompanying report No. 291.)

†295. Sketch plan of Gaspé oil Fields, Quebec showing location of wells. Scale 2 miles to 1 inch. (Accompanying report No. 291.)

†296. Map showing gas and oil fields and pipe-lines in southwestern Ontario. Scale 4 miles to 1 inch. (Accompanying report No. 291.)

†297. Geological map of Alberta, Saskatchewan, and Manitoba. Scale 35 miles to 1 inch. (Accompanying report No. 291.)

†298. Map, geology of the forty-ninth parallel, 0·9864 miles to 1 inch. (Accompanying report No. 291.)

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†302. Map showing location of main gas line, Bow Island, Calgary. Scale 12½ miles to 1 inch. (Accompanying report No. 291.)

†311. Magnetometric map, McPherson mine, Barachois, Cape Breton county, Nova Scotia—by A. H. A. Robinson, 1913. Scale 200 feet to 1 inch.

†312. Magnetometric map, iron ore deposits at Upper Glencoe, Inverness county, Nova Scotia—by E. Lindeman, 1913. Scale 200 feet to 1 inch.

†313. Magnetometric map, iron ore deposits at Grand [illegible]a, Cape Breton county, Nova Scotia—by A. H. A. Robinson, 1913. Scale 200 feet to 1 inch.

Address all communications to—

DIRECTOR MINES BRANCH,
DEPARTMENT OF MINES,
SUSSEX STREET, OTTAWA.

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